RECLAMATION
Managing Water in the West

Technical Evaluation of the Gold King Mine Incident

San Juan County, Colorado

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

October 2015

Mission Statements

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Peer reviewed by:

U.S. Geological Survey
U.S. Army Corps of Engineers

U.S. Department of the Interior
Bureau of Reclamation
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Technical Approval

The results, findings, and recommendations provided in this *Technical Evaluation of the Gold King Mine Incident* are technically sound and consistent with current professional practice.

Prepared by Michael J. Gobla, M.S., P.E.	October 13, 2015 Date
Prepared by Christopher M. Gemperline, M.S., P.E.	October 13, 2015 Date
Prepared by Leslie W. Stone, M.S., P.G.	October 13, 2015 Date
Peer reviewed by David Rees Gillette, PhD, P.E.	October 13, 2015 Date
Peer reviewed by Randall W. Jibson, PhD	15 oct 2015 Date
Peer reviewed by Richard S. Olsen, PhD, P.E.	2015 oct 16 Date

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Abbreviations and Acronyms

ARSG	Animas River Stakeholders Group, a non-government organization founded to foster cleanup of the mines and mining wastes impacting the Animas River
BOR	Bureau of Reclamation
DOI	U.S. Department of the Interior
DRMS	Division of Reclamation, Mining and Safety, a part of the State of Colorado Department of Natural Resources
EPA	U.S. Environmental Protection Agency, a federal regulatory agency
HDPE	High-density polyethylene, a plastic resin used to manufacture pipe, geomembranes, and other products that have a high resistance to chemical attack
MSHA	Mine Safety and Health Administration, a federal regulatory agency that issues and enforces mine safety regulations at operating mines
OSC	On Scene Coordinator, an EPA official title
SMCRA	Surface Mining Control and Reclamation Act. Federal legislation enacted in 1977 to establish the Office of Surface Mining and Reclamation Enforcement to regulate surface and underground coal mining and establish a fund for the reclamation of abandoned coal mines.
USACE	U.S. Army Corps of Engineers
USCS	Unified Soil Classification System
USGS	U.S. Geological Survey

Executive Summary

On the morning of August 5, 2015, mine reclamation activities led by the U.S. Environmental Protection Agency (EPA) onsite project team triggered an uncontrolled rapid release of approximately 3 million gallons of acid mine water from the Gold King Mine located about 5 miles north of Silverton, Colorado. Commonly referred to as a "mine blowout," the outflow carried with it iron-oxyhydroxide sediments that had deposited inside the mine workings. The iron-oxyhydroxide absorbed heavy metals when it formed in the mine, and when released it changed the acid water to a vivid orange-brown color. The blowout eroded soil and rock debris from the mine portal, eroded pyritic rock and soil from the adjoining waste-rock dump, and eroded road-embankment fill from several downstream unpaved road stream crossings. Most of the eroded rock, gravel, and sand were deposited in Cement Creek. As the flow continued downstream, deposition of small amounts of soil particles mixed with orange-brown iron-oxyhydroxide precipitates containing heavy metals continued to occur along the Animas River and San Juan Rivers until the plume reached Lake Powell in Utah on August 14, 2015.

EPA requested an independent technical evaluation of the Gold King Mine incident. The evaluation provided in this report was performed by the Bureau of Reclamation (BOR) and peer reviewed by the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE).

In preparing this report, BOR found that the conditions and actions that led to the Gold King Mine incident are not isolated or unique, and in fact are surprisingly prevalent. The standards of practice for reopening and remediating flooded inactive and abandoned mines are inconsistent from one agency to another. There are various guidelines for this type of work but there is little in actual written requirements that government agencies are required to follow when reopening an abandoned mine.

The uncontrolled release at Gold King Mine was due to a series of events spanning several decades. Groundwater conditions in the upper reaches of Cement Creek have been significantly altered by the establishment of extensive underground mine workings, the extension of the American Tunnel to the Sunnyside Mine, and the subsequent plugging of the American Tunnel. The final events leading to the blowout and uncontrolled release of water occurred due to a combination of an inadequately designed closure of the mine portal in 2009 combined with a misinterpretation of the groundwater conditions when reopening the mine portal in 2014 and 2015.

In attempting to reopen the Gold King Mine, the EPA, in consultation with the Colorado Division of Reclamation, Mining and Safety (DRMS), concluded the adit was partially full of water based on excavations made in 2014 and 2015 into

the downstream side of backfill placed at the portal. Adit seepage was observed in the downstream excavations to be emerging at an elevation about 6 feet above the adit floor. It was incorrectly concluded that the water level inside the mine was at a similar elevation, a few feet below the top of the adit roof. This error resulted in development of a plan to open the mine in a manner that appeared to guard against blowout, but instead led directly to the failure.

The collapsed material in the adit and the backfill added in 2009 were derived from the collapsed rock and soil that contained a significant amount of clay. It was not a typical roof collapse comprised of mostly cohesionless broken rock. The clay content contributed to the significant attenuation (head loss) of flow in the collapsed debris and the placed backfill as the mine water flowed through it. Also, deposition of iron-oxyhydroxide sediments inside the mine likely contributed to additional reductions in the seepage flow as the sediment layer grew thicker with the passage of time. Changes in seepage were observed and documented in photographs in both 2014 and 2015, but its implications with respect to attenuation of the flow through the fill were not accounted for.

After the EPA project team concluded that the adit was not full to the top with water, they implemented a plan to open the mine in a manner similar to the one used successfully to reopen the adit at the nearby Red and Bonita Mine in 2011. The plan consisted of excavating the fill to expose the rock crown over the adit but leave the fill below the adit roof in place. Then a steel pipe ("stinger") would be inserted through the fill and into the mine pool, a pump would be attached, and the water in the mine would be pumped down.

A critical difference between the Gold King plan and that used at the Red and Bonita Mine in 2011 was the use in the latter case of a drill rig to bore into the mine from above and directly determine the level of the mine pool prior to excavating backfill at the portal. Although this was apparently considered at Gold King, it was not done. Had it been done, the plan to open the mine would have been revised, and the blowout would not have occurred.

The incident at Gold King Mine is somewhat emblematic of the current state of practice in abandoned mine remediation. The current state of practice appears to focus attention on the environmental issues. Abandoned mine guidelines and manuals provide detailed guidance on environmental sampling, waste characterization, and water treatment, with little appreciation for the engineering complexity of some abandoned mine projects that often require, but do not receive, a significant level of expertise. In the case of the Gold King incident, as in many others, there was an absence of the following:

1. An understanding that water impounded behind a blocked mine opening can create hydraulic forces similar to a dam.

2. Analysis of potential failure modes.

3. Analysis of downstream consequences if failure were to occur.

4. Engineering considerations that analyze the geologic and hydrologic conditions of the general area.

5. Monitoring to ensure that the structure constructed to close the mine portal continues to perform as intended.

6. An understanding of the groundwater system affecting all the mines in the area and the potential for work on one mine affecting conditions at another.

This evaluation report provides a detailed account of the basis for these findings and recommendations for prudent engineering considerations that EPA (and others) should consider to preclude the occurrence of similar incidents.

It is important to note that although the USACE peer reviewer agreed that the report properly describes the technical causes of the failure, he had serious reservations with the chronology of events internal to EPA from the day of the telephone call to BOR and up to the day of the mine failure. He pointed out that the actual cause of failure is some combination of issues related to EPA internal communications, administrative authorities, and/or a break in the decision path, and that the report was non-specific regarding the source of information concerning EPA documents and interviews with EPA employees and the onsite contractor. The USACE believes that the investigation and report should have described what happened internal within EPA that resulted in the path forward and eventually caused the failure. The report discusses field observations by EPA (and why they continued digging), but does not describe why a change in EPA field coordinators caused the urgency to start digging out the plug rather than wait for BOR technical input as prescribed by the EPA project leader.

The BOR Evaluation Team (evaluation team) believed that it was hired to perform a technical evaluation of the causes of the incident, and was not asked to look into the internal communications of the onsite personnel, or to determine why decisions were made. The evaluation team did not believe it was requested to perform an investigation into a "finding of fault," and that those separate investigative efforts would be performed by others more suitable to that undertaking.

Introduction

This report documents the technical evaluation of the August 5, 2015, uncontrolled release of mine water from the Gold King Mine in San Juan County, Colorado (figure 1). The purpose of the technical evaluation is to identify the causes of the event, the lessons learned, and to provide recommendations to avoid future incidents. It is not intended to document or evaluate the downstream consequences and impacts of the spill.

The evaluation included consideration of the site and regional geology, and the groundwater system at the Gold King Mine and the surrounding area. The history of mining operations in the area is presented, along with a brief summary of the mine drainage releases into Cement Creek and the Animas River. The mine reclamation efforts at the mine workings in the area are also summarized.

Based on this understanding of the site conditions and historical activities, the evaluation team provides a chronologic accounting of the remediation efforts at Gold King Mine from 2009 to the present. The plans to open the mine are presented, along with an EPA account of the blowout incident on August 5, 2015, and subsequent actions taken to repair and stabilize the site in and around the mine portal.

The evaluation team then provides the results of an engineering analysis of the conditions and decisions that led to the incident, including a review of potential failure modes, the extent of the mine pool, the potential for attenuation of flow from the mine pool through the backfill "plug" blocking the mine portal, and an evaluation of the failure of the "plug."

The evaluation team presents the current state of practice in reopening potentially flooded adits. The report concludes with a summary of findings focused on the causes of the August 5, 2015, incident at Gold King Mine and recommendations to consider to avoid future incidents.

Figure 1.—Photograph of the Gold King Mine looking west. The red arrow points to the location of the mine blowout, which occurred on August 5, 2015.

Composition of the Evaluation Team

EPA requested technical assistance from the U.S. Department of Interior (DOI) and USACE to perform an independent review of the cause of the sudden release from Gold King Mine and steps that could be taken to preclude similar incidents at other sites in the future. DOI turned to BOR to lead the technical evaluation and coordinated with USACE and USGS for peer review of the work performed by BOR.

The evaluation team includes the following individuals:

- Michael J. Gobla, M.S., P.E., Supervisory Civil Engineer and Manager of Geotechnical Engineering Group 3, Technical Service Center, Bureau of Reclamation

- Christopher M. Gemperline, M.S., P.E., Geotechnical Engineer, Geotechnical Engineering Group 3, Technical Service Center, Bureau of Reclamation

- Leslie W. Stone, M.S., P.G. Division Chief, Geotechnical Engineering Services Division, Technical Service Center, Bureau of Reclamation

The peer review team includes the following individuals:

- Richard S. Olsen, Ph.D., P.E., Senior Geotechnical Engineer, U.S. Army Corps of Engineers
- Randall W. Jibson, Ph.D., Research Geologist, U.S. Geological Survey
- David Rees Gillette, Ph.D., P.E., Engineering Technical Specialist, Geotechnical Group 4, Technical Service Center, Bureau of Reclamation

The BOR has provided technical assistance to the EPA in the past. Mr. Gobla, the lead investigator, has performed work for EPA Regions 4, 8, and 10 on mine sites. Mr. Gemperline has advised EPA Region 8 on a few small mine cleanup projects.

For the evaluation of the blowout incident, BOR visited the Gold King Mine site on three occasions to view conditions and gather information. Conversations were held with all of the people present on the day of the blowout, and follow up telephone conversations were held with the EPA and DRMS personnel. Two soil samples were taken and tested to determine soil properties. There was not adequate time to conduct all of the soil tests that were desired, but the essential tests to understand the nature of the soil debris and backfill blocking the adit were performed. Copies of documents about the site activities and numerous photographs were obtained from EPA and DRMS and reviewed. A literature review was conducted to understand the current state of practice regarding mine remediation followed up by some telephone conversations to other state and federal agencies.

Location

The Gold King Mine is located one-half mile northeast of Gladstone, San Juan County, Colorado, in the SE ¼ of Section 16, Township 42 North, Range 47 West of the New Mexico Principal Meridian. The Gold King Mine adit portal lies above the North Fork of Cement Creek at an elevation of approximately 11,400 feet. The portal is shown on topographic maps as the "Upper Gold King," and the "Gold King Mine" shown on the maps at Gladstone is now known as the American Tunnel (figure 2). The mine is in an alpine environment and experiences significant precipitation mostly in the form of snow from late fall through winter and spring followed by frequent rain and occasional hail during the summer months. Snow accumulations average 15 feet. Access to the site for fieldwork is limited to periods when there is no snow cover, generally late June through early October.

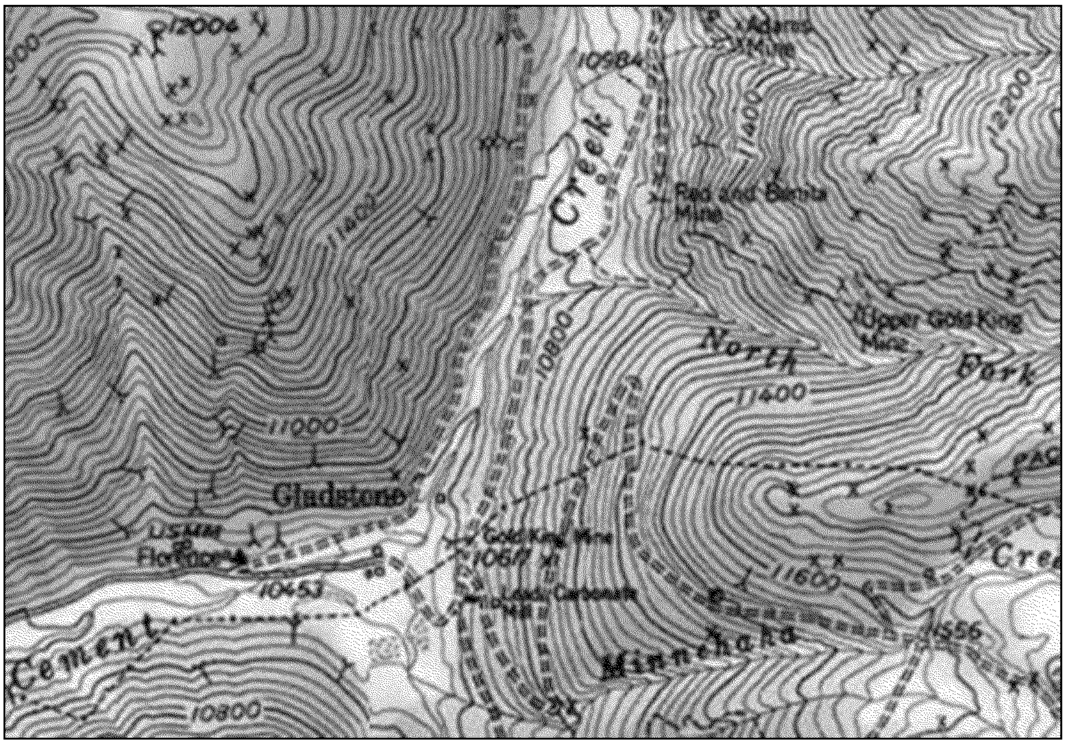


Figure 2.—Illustration showing part of the USGS Ironton 7.5-minute quadrangle topographic map showing the Red and Bonita Mine, the "Upper Gold King Mine" (Gold King Level 7), and the "Gold King Mine" (American Tunnel).

Geology at the Gold King Mine

The Gold King Mine is located in the northern portion of the Silverton Caldera, a feature in an extensive volcanic field in southwest Colorado that was active during the Tertiary Period (25 to 35 million years ago). Bedrock at the site is the Burns Formation, comprised of quartz-latite flows, flow breccias, and tuffs. The Gold King Mine is near the western margin of a northeast-trending structural-collapse feature known as the Eureka Graben (figure 3). An intricate system of radial fractures and faults developed around the northwest portion of the San Juan Caldera in the vicinity of the Eureka Graben. The Ross Basin and Bonita Faults form a part of the southwestern border of the Eureka Graben. Major faults and veins in the Silverton area have been documented by the USGS as a part of a water quality study for the Animas River watershed headwaters (Church, and others, 2007b).

Several mineralizing events altered the site. About 25 million years ago, a quartz-monzonite stock intruded south of the mine and 11 million years ago, the Red Mountain Stock intruded west of the site (Free, and others, 1990). These intrusions were likely heat sources for the mineralizing events that deposited metals at the mine and altered the surrounding rocks.

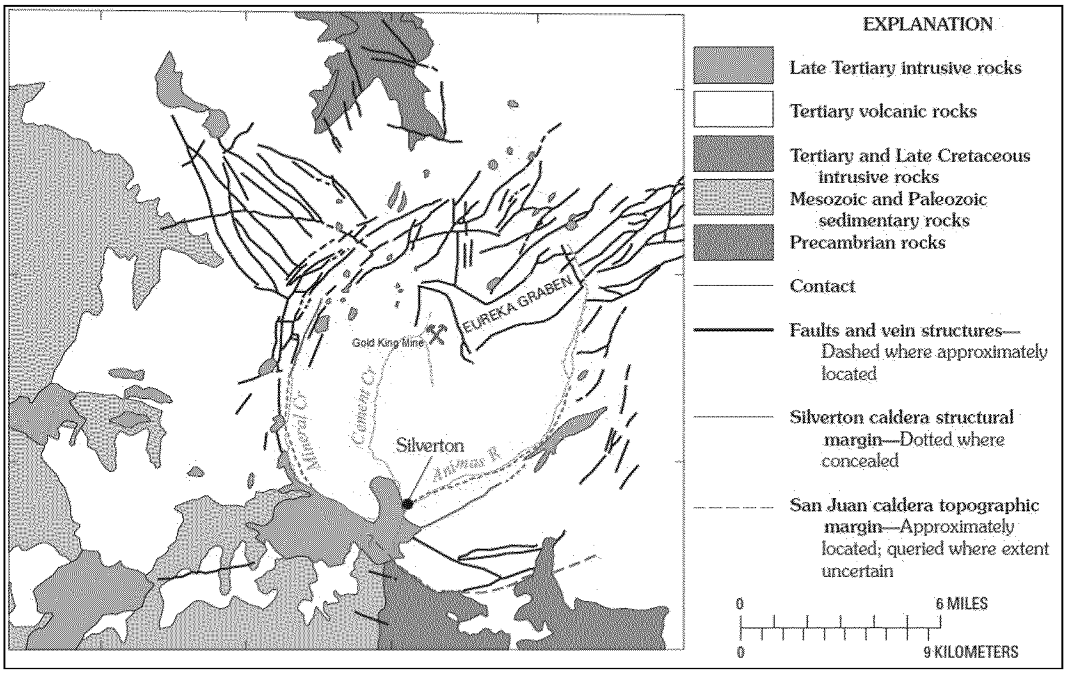


Figure 3.—Generalized regional geology in the vicinity of the Gold King Mine. Illustration taken from USGS Professional Paper 1651 (Church, and others, 2007b).

Most of the bedrock in the vicinity of the Gold King Mine is highly fractured and is reported as having extensive alteration with local zones of vein-related quartz-sericite-pyrite altered rock in the portal area (Church, and others, 2007b). In addition to the alteration caused by past hydrothermal activity, the near-surface rocks have been subjected to weathering resulting in the formation of a soil mantle overlying altered bedrock. Acid-rock drainage occurs both naturally and as a consequence of past mining operations. Ferricrete, which consists of deposits of soil and rock particles cemented by iron-oxyhydroxide, occurs extensively along surface water flow pathways as a byproduct of the acid drainage. The acid drainage has been studied extensively (Church, and others, 2007a, 2007b).

The Gold King Mine workings are located in an area where northeast-trending faults of the Eureka Graben intersect the northwest-trending Bonita Fault. In the mine, the intersection of these structural features resulted in mineralized vein systems interspersed with numerous irregular blocks of barren rock (Burbank and Luedke, 1969).

The metallic deposits at the mine occur in two northeast-trending, nearly parallel, steeply inclined veins called the Gold King lode and the Davis lode. In the highest levels of the mine, the lodes are nearly vertical and separated by about 50 to 80 feet. In the lower levels, the dip of the lodes transition to the northwest, and their separation gradually decreases until they converge near the lowest level of the mine. Flatter lying, northwest-dipping veins were encountered in several levels but were only mined for short distances (Ransome, 1901; Free, and others, 1990).

Groundwater System

Two principal sources of groundwater are present in the Cement Creek and Sunnyside Basin areas. Shallow groundwater is confined to thin layers of topsoil and decomposed bedrock. This water flows downslope into the existing drainages. A deeper aquifer is fed by inflow of surface water and snowmelt into natural fractures in the rock and mine workings that intersect the surface.

The groundwater regime in the Gold King area, upper Cement Creek, and the Sunnyside Basin is dominated by interaction of extensive underground mine workings and a very complex system of fractures related to the various volcanic flows, tuffs, and breccias; formation of the Eureka Graben; and the Bonita Fault.

Sufficient data were not found during this review on subsurface fracture, joint, and fault data to make definitive statements regarding sources and quantity of groundwater in the Gold King area. Rans ome (1901) noted the lack of water in the Gold King Mine when the mine was at Level 4; however, once mining shifted to Level 7, a historical photograph (figure 5) taken prior to the mine closing shows water flowing down the waste-rock dump at the Level 7 portal. This would indicate water entering the mine between Levels 4 and 7, but no records were found to indicate if this water was entering laterally, vertically, or both.

For this review, DRMS supplied BOR with a copy of a 1993 report prepared for the Sunnyside Gold Corporation titled "Evaluation of the Hydraulic and Hydrochemical Aspects of Proposed Bulkheads, Sunnyside Mine, March 12, 1993," by Simon Hydro-search of Reno, Nevada. This report concluded that permeability in the area is anisotropic and is greater in a northeast/southwest direction because of the dominant fracture orientation of the Eureka Graben. They also speculated that the original direction of groundwater movement prior to mining was from the Sunnyside Basin toward Cement Creek and that this groundwater flow direction would be reestablished once the bulkheads were placed in the American Tunnel and other tunnels connected to the Sunnyside Mine. Assuming a static water elevation of 11,500 feet after installation of the American Tunnel bulkheads, the report estimated a travel time for water through bedrock from the Sunnyside Basin to Cement Creek of 150 years. However, the report speculated that the travel time would reduce with higher groundwater levels, with an estimated travel time of four months to Cement Creek at an elevation of 12,250 feet. The 1993 report theorized a diffused discharge of groundwater along Cement Creek between the Mogul Mine on north to the Silver Ledge Mine near Gladstone on the south. There was no indication in the 1993 report that plugging the American Tunnel would result in significant increased inflow into the Gold King Mine workings.

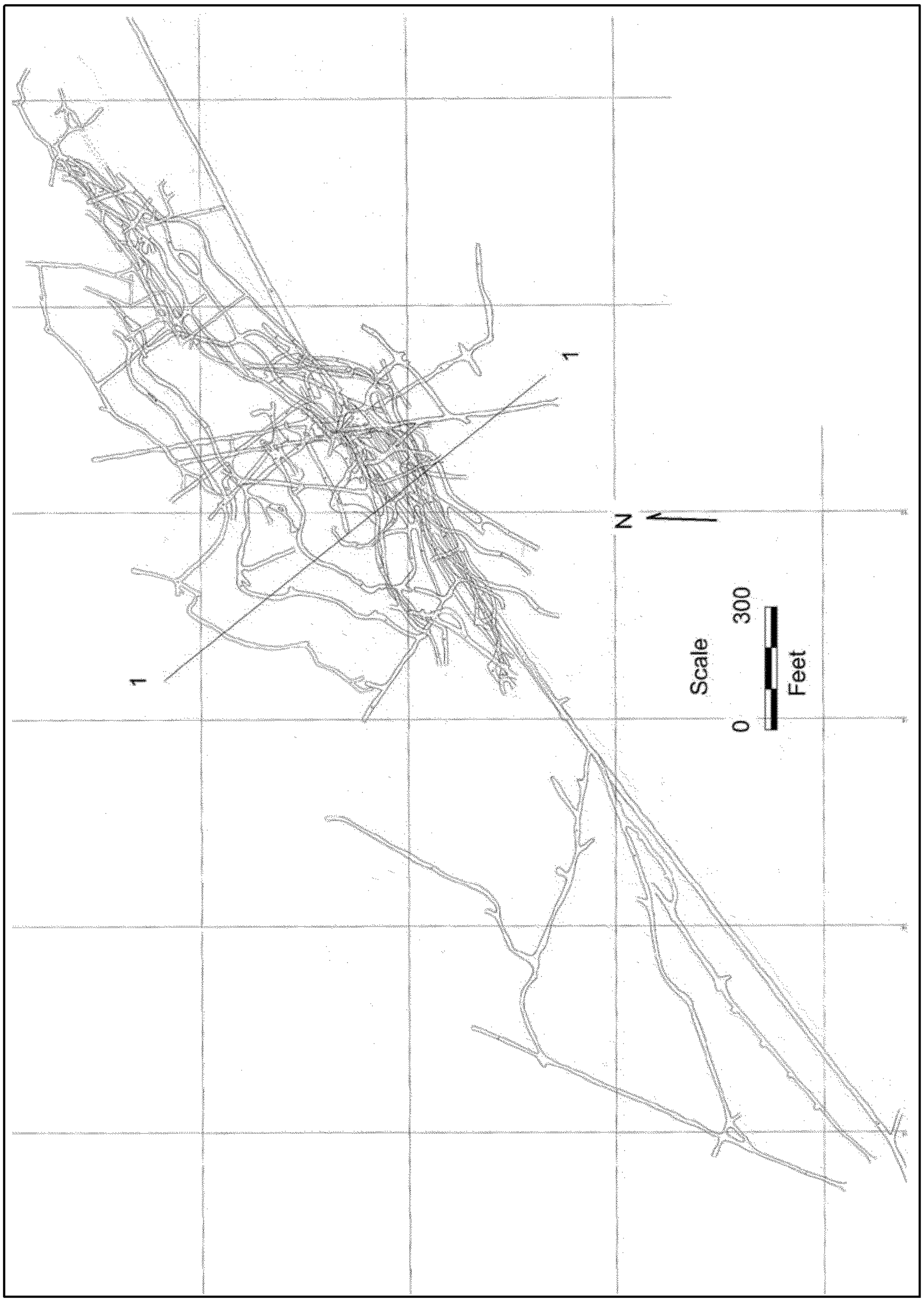


Figure 4a.—Map showing all of the Gold King Mine levels and the American Tunnel superimposed. The figure also shows the location of cross-section 1-1 (shown in figure 4b) that was drawn to show the relative locations of the Gold King Mine underground workings.

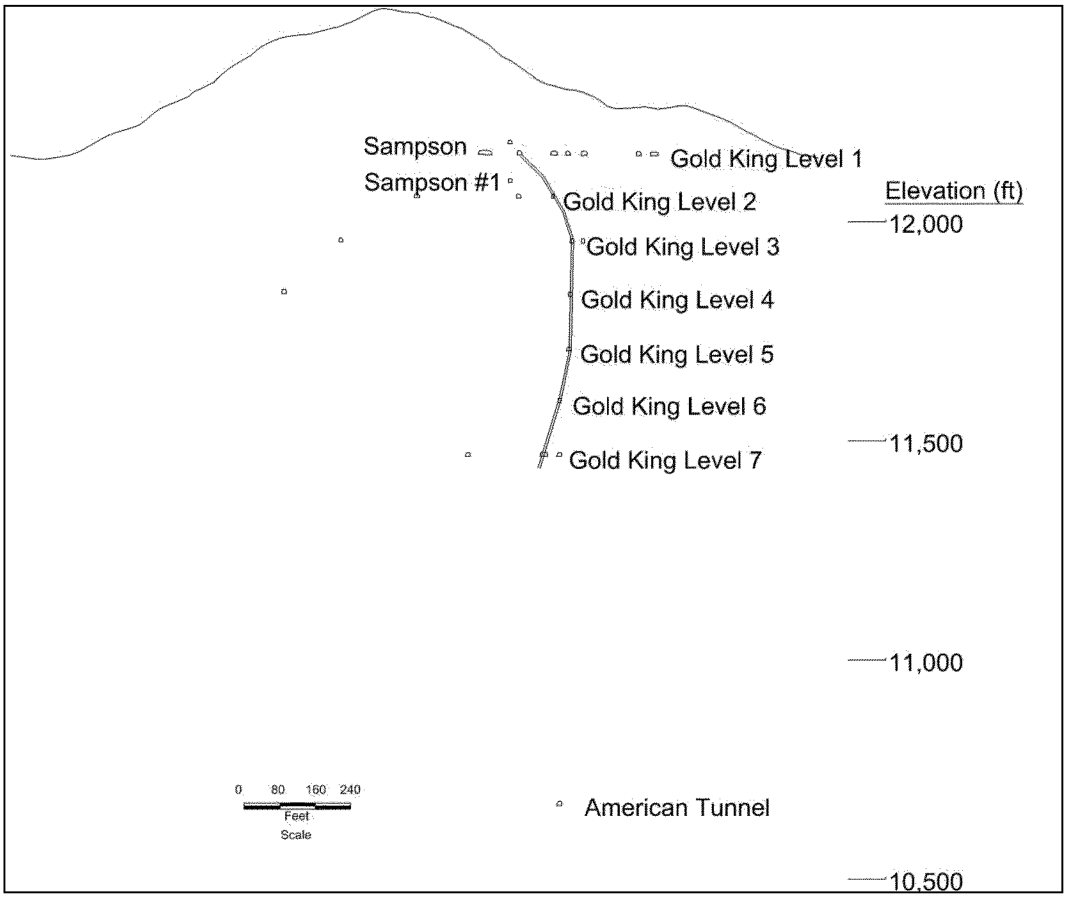


Figure 4b.—Cross-section showing the relative locations and elevations of the American Tunnel in relation to the levels of the Gold King Mine.

Mining History

Gold was discovered in the San Juan Mountains in 1860, but development did not begin until 1871 when the Little Giant Mine was developed on a small scale (Church, and others, 2007b). Numerous other discoveries were made, but mining operations remained on a small scale for a decade until the Denver and Rio Grande Railroad was extended to Silverton and began operations. The railroad provided an efficient connection to a smelter in Durango, Colorado, and production increased ten-fold from approximately 1,000 tons per year to more than 10,000 tons.

On August 18, 1873, Reuben J. McNutt staked the Sunnyside mining claim (Bird, 1986). The mining claim changed ownership but soon became a notable producer. By 1896, the Silverton Northern Railroad was extended to Eureka, Colorado, to serve the Sunnyside Mine, which grew into the most productive mine in the district. It opened and closed many times during its life.

The transformation of the Lower Gold King Adit into the American Tunnel starting in 1959 was successful and gave new life to the Sunnyside Mine, with production commencing in June 1961 and lasting until 1971. The mine opened and closed several more times during the next 20 years. It was the largest employer in San Juan County, and it survived a notorious blowout in 1978 that drained Lake Emma and required two years to repair. Operations finally stopped on August 15, 1991. The Sunnyside is credited with a production of more than 7 million short tons of ore over its life span of 118 years.

Production at the Gold King Mine started in 1886. By 1899, the Silverton, Gladstone, and Northerly Railroad was built to Gladstone, where the Gold King Mine had become a prominent producer. The mine was operated continuously until 1917 with a production of 665,000 tons of ore averaging 14.65 g/t gold, 74.32 g/ton silver, 0.71% lead, and 0.52% copper (Free, and others, 1990). There was very minor production for a few more years. Mining operations ended around 1923.

Production mining was carried out on seven levels (figure 4b). Initially, the mine was accessed at Level 1 through a portal at elevation 12,160 feet. Mining was not carried out below Level 7 due to a decrease in precious metal content with depth (Free, and others, 1990). The Lower Gold King, at an approximate portal elevation of 10,617 was originally driven 6,233 feet as an exploratory tunnel into the Gold King vein system but was not developed. It was renamed the American Tunnel in 1959 and extended in 1960 and 1961 to drain the Sunnyside Mine workings, but no additional work was done on the Gold King veins from the American Tunnel (Burbank and Luedke, 1969).

Above the Gold King Mine Level 7, the four "flat lying" (gently inclined) veins were explored in the 1970s and 1980s, and a significant gold resource was reported (Free, and others, 1990). The original Level 7 adit was caved in. To facilitate the exploration work, a new adit was driven from the Level 7 waste-rock dump at a location that is about 100 feet to the east of the original adit. Like the original Level 7 adit, the 1970's adit later caved and, in 2015, it was the site of the blowout.

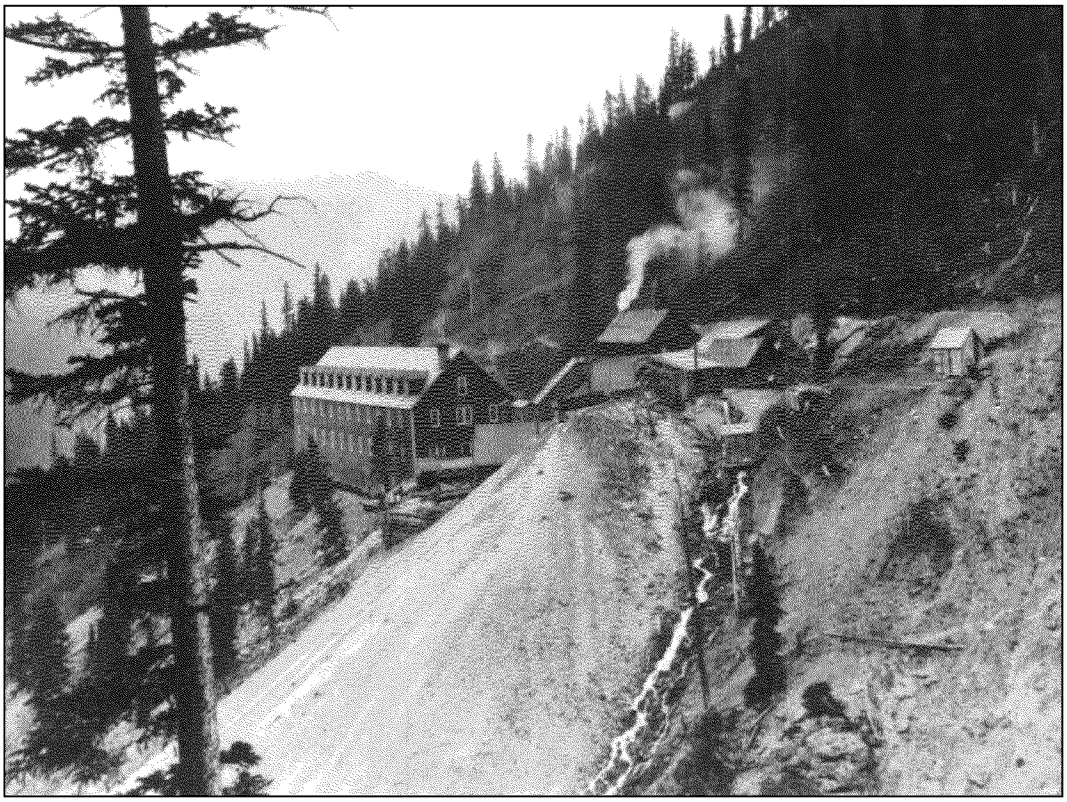


Figure 5.—Historical photograph of the Gold King Mine Level 7 taken prior to the mine closing in 1923. Note the drainage flow down the side of the waste-rock dump.

Figure 6 shows the Sunnyside Mine workings in relation to the nearby Mogul, Gold King, and Red and Bonita Mines.

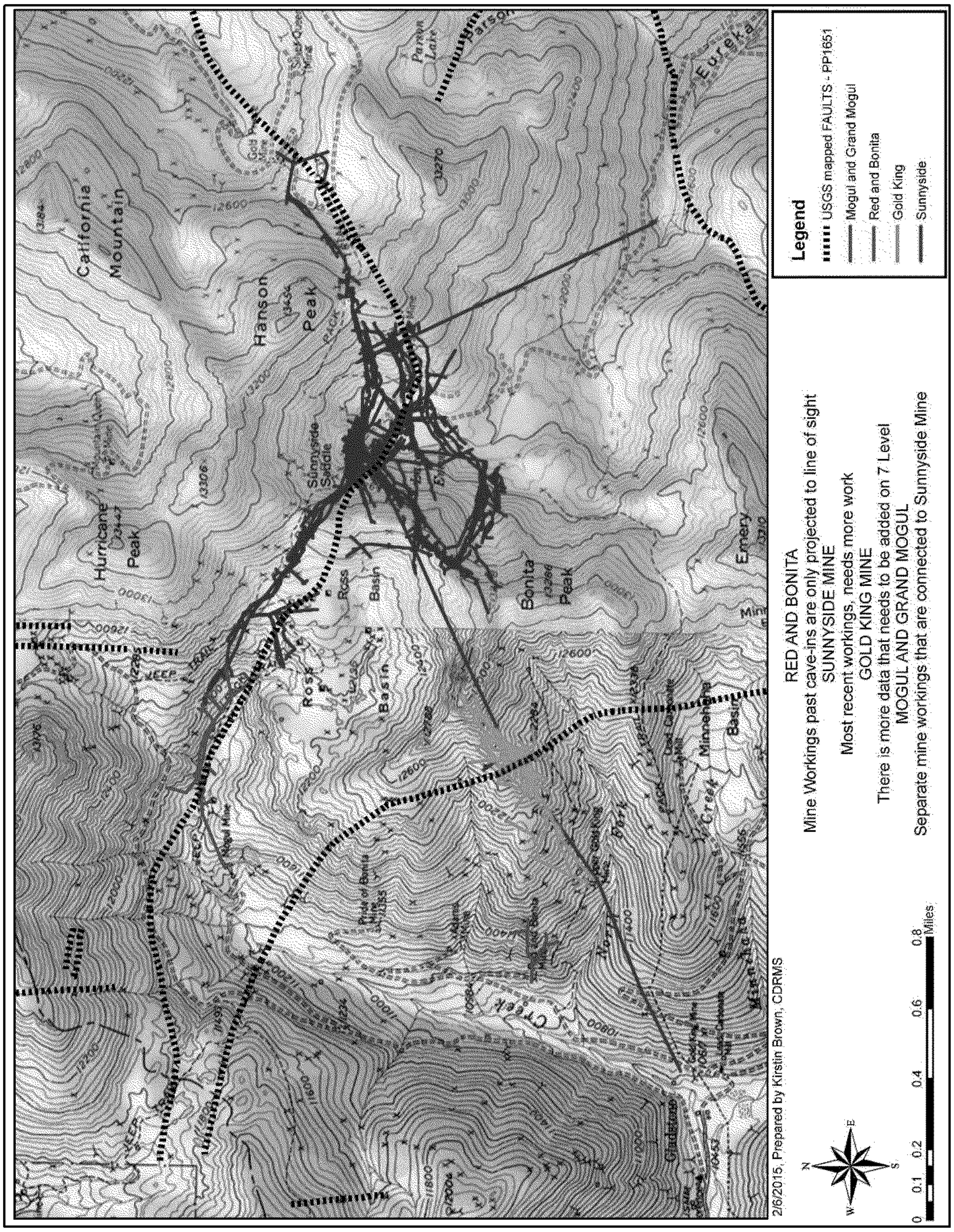


Figure 6.—Map showing topography and the location of the Sunnyside, Gold King, and Red and Bonita Mines workings in the Eureka mining district (graphic prepared by Kirstin Brown of the Colorado Division of Reclamation, Mining, and Safety on February 6, 2015).

Mining Releases to the Animas River

Mining in the San Juan Mountains has had a long-term environmental impact on the Animas River. Cement Creek and other drainages receive acid drainage that is naturally formed. These creeks were biologically dead prior to any mining activity in the area; however, more than 100 years of mining have significantly increased the environmental impacts and magnified the downstream effects. During the operation of mills, from 1890 to 1913, it is estimated that 4.3 million tons of tailings were discharged directly into the streams (Church, and others, 2007a). The Animas River was so contaminated that in 1902 the City of Durango had to build a new reservoir for a public water supply. A change to flotation milling and construction of tailings-dam impoundments greatly reduced the releases but in total, over the life of the watershed, it is estimated that 8.6 million tons of tailings have ended up in the river environment. There were also two notable releases prior to the Gold King Mine incident.

On June 8, 1974, one of the tailings dams at the Sunnyside's mill in Silverton failed due to melting ice eroding a breach and releasing approximately 116,000 tons of sulfidic mine tailings that rapidly flowed downstream into the Animas River (Church, and others, 2007b). Water intakes in Durango, Colorado, and Farmington New Mexico, had to be closed for a week as a result of the accidental release (Bird, 1986).

On June 4, 1978, an estimated 500 million gallons of mud and water from Lake Emma suddenly broke into the Sunnyside Mine and blew out of the American and Terry Tunnels. The flow carried with it wrecked mining equipment, pulverized mine timbers, and sulfide rock debris. Although a drill hole indicated that the rock extended up another 70 feet to the lake, the drill missed a narrow zone where alpine glaciers had scoured the rock nearly all the way to the location of the mining. Shortly before the event, two of the miners working in the stope complained that water was coming in and that it was unsafe to proceed further up toward the lake. Fortunately, the event occurred on a Sunday, the one day when the Sunnyside Mine was not in operation. Had it been in operation, a crew of 125 miners would have been killed by the violent inrush and subsequent blowout. It took two years to remove the black mud and repair and reopen the mine (Bird, 1986). The mine operated for another decade, finally closing in 1991.

Summary of Abandoned Mine Remediation in the Upper Animas River Watershed

In 1990, the State of Colorado Water Quality Control Division initiated studies to set water quality standards for the Upper Animas Watershed. At their urging, the Animas River Stakeholders Group (ARSG) was formed in 1994. The objectives of the group were as follows (Russell, 2000):

- Identify major sources of environmental problems from the numerous abandoned mine sites in the watershed.
- Determine the relative contributions of metal loading to the river from these sources.
- Improve water quality, where possible, at these sites.

The group was composed of local residents; mining companies; and officials from local, state, and Federal government agencies. In 1997, DOI started an Abandoned Mined Lands Initiative to study the effects of abandoned mines on water quality and named the Animas River as a pilot project site. Through the efforts of the ARSG it was determined that the bulk of the metals loading the Animas River was coming from about 80 sites out of the 4,500 in the watershed (Church, and others, 2007a).

As conditions change, the ARSG revises its ranking and prioritization of sites. In 1999, they ranked 14 draining adits—the Silver Ledge was the worst, followed by the Mogul (Russell, 2000). The Red and Bonita and the Gold King Mines were not of concern at the time because they had minimal mine drainage flow. After installing hydraulic bulkheads in the Mogul Mine in 2003, increased flows began to come from the Red and Bonita and the Gold King Mines, and eventually the ARSG listed these as their top two priorities for remediation. Flow from the Red and Bonita Mine contains very high levels of zinc (Way, 2014a). Flow from Gold King Mine contains lower levels of zinc, but is more acidic.

Reclamation of the Sunnyside Mine

In 1991 when the Sunnyside Mine closed, acid drainage flowing from the American Tunnel was impacting Cement Creek. A remediation program to minimize acid drainage and to reclaim surface lands impacted by mine wastes was initiated by the mining company. The company also sold some properties, including the Mogul and Gold King Mines, to others interested in resuming gold mining. Sunnyside was required to treat water. A small water-treatment plant

was installed at Gladstone to treat the American Tunnel discharge, which had grown to about 1,700 gpm. In May 1996, a consent decree was signed between the Colorado Department of Health and Environment and Sunnyside Gold, Inc., to allow the discontinuation of perpetual water treatment. An essential part of the agreement was that Sunnyside would undertake reclamation of numerous acid sources in the area to offset the residual acid seepage expected to continue to discharge from the American Tunnel. With the additional waste removal and reclamation work underway, they commenced the installation of hydraulic bulkheads. The valve on the American Tunnel bulkhead was closed in October 1996. Additional hydraulic bulkheads were placed in 1997 at the American Tunnel, the Gold Prince Mine, and other locations. A total of $10 million was expended on this work (Church, and others, 2007a). The company also injected a lime slurry into the Sunnyside Mine to neutralize the water, but this did not have a lasting effect and the seepage has turned acidic again. As a result of the hydraulic bulkheads, flow from the American Tunnel decreased from 1,700 gpm to about 100 gpm (figure 7).

Figure 7.—Photograph showing the seepage outflow from the drain pipe at the American Tunnel at Gladstone, Colorado, as it appeared on September 3, 2015, with about 100 gpm of acid water flowing out.

In 2000, acid drainage began discharging from the Mogul Mine. This was likely the consequence of rebounding groundwater levels and a rising mine pool caused by the installation of hydraulic bulkheads in the Sunnyside Mine. By 2002, significant flow was discharging from the Red and Bonita and the Gold King Mines Level 7 adits. In 2003, bulkheads were added to the Mogul Mine by the Sunnyside Mine owners (figures 8 through 10).

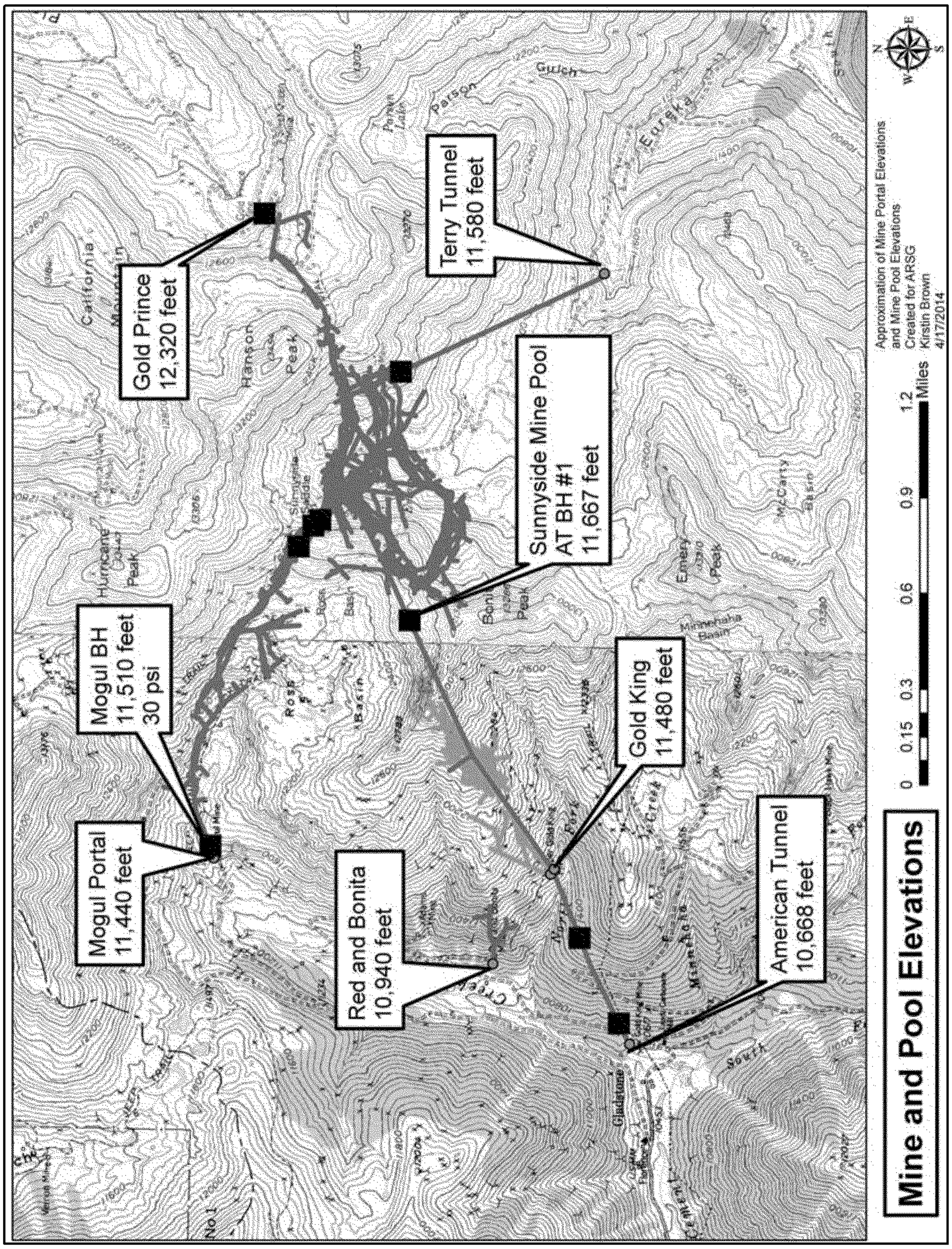


Figure 8.—Map showing topography; potentially flooded mine workings in the Sunnyside, Gold King, and Red and Bonita Mines; and the location of bulkheads (BH) represented by black squares. The approximate elevations of the mine adits are presented along with readings from the Sunnyside Mine pool (11,667 ft.) and the Mogul Mine pool (11,510 feet) (graphic prepared by Kirstin Brown of DRMS on April 17, 2014).

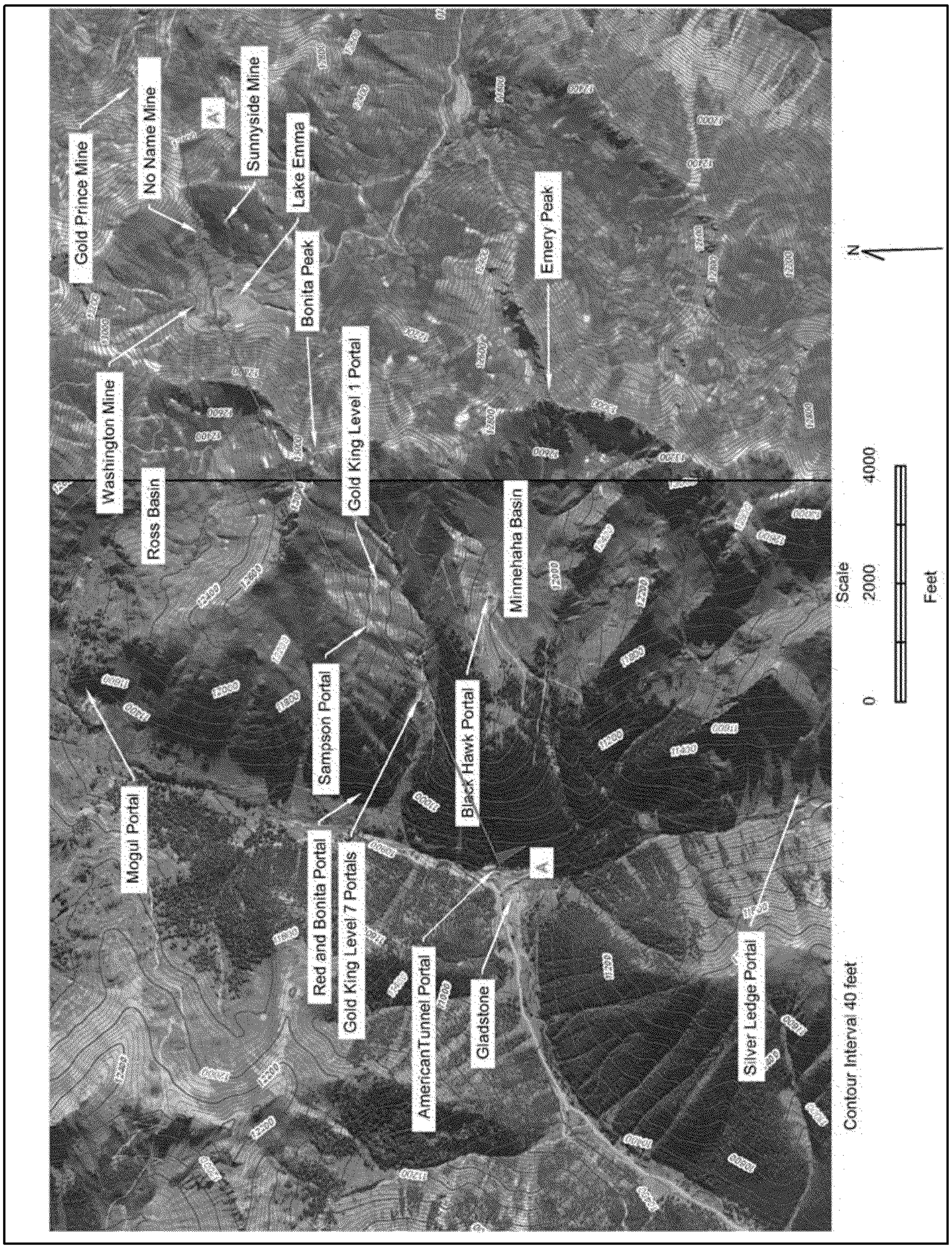


Figure 9a.—Illustration showing the location of the Gold King, Sunnyside, and other mines discussed in this report. The figure also shows the location of a cross-section (shown in figure 9b) that was drawn to show the relative locations of the Sunnyside Mine and the Gold King Mine underground workings.

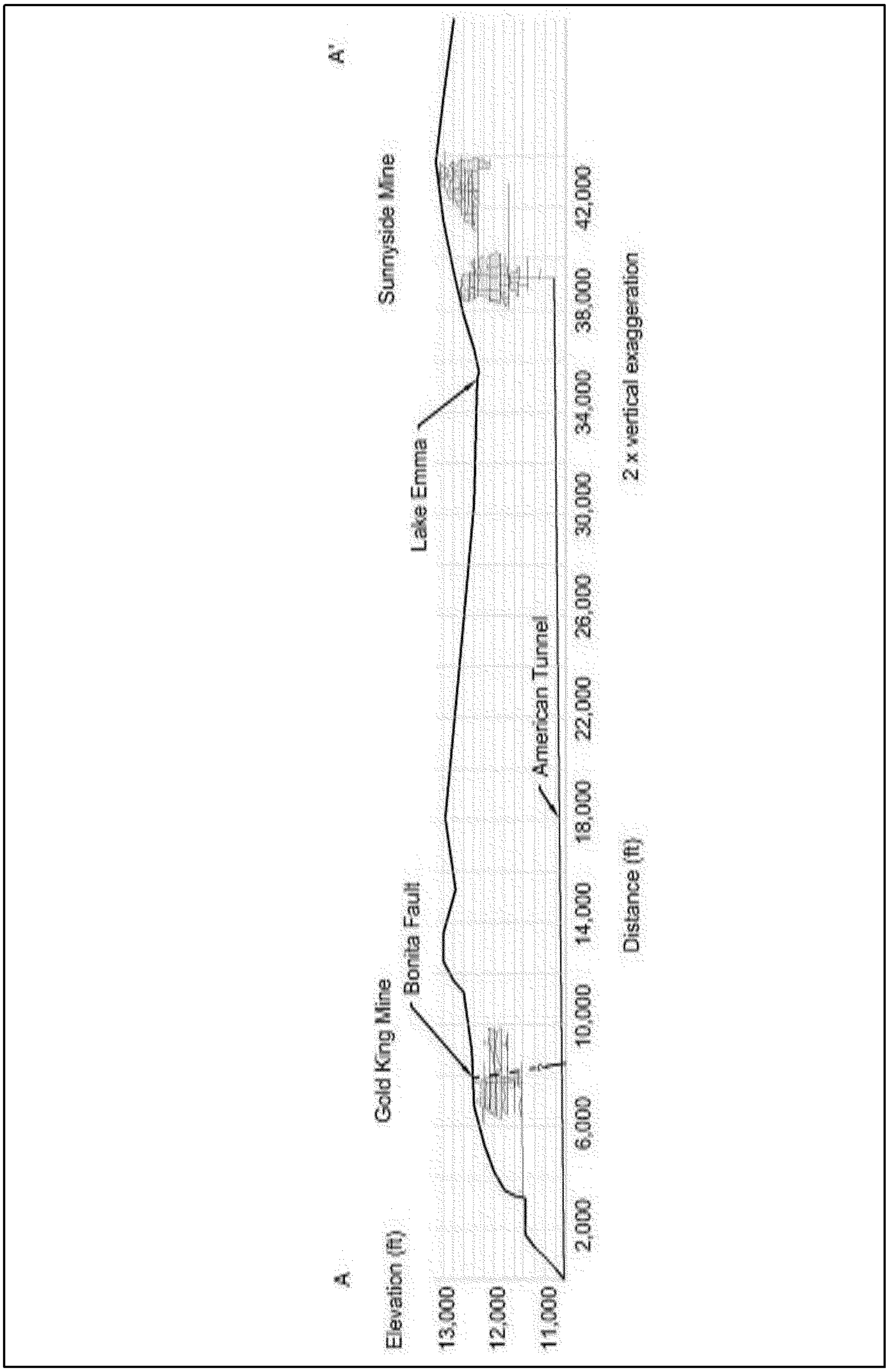


Figure 9b.—Cross-section showing the location of the Sunnyside Mine, Gold King Mine, and American Tunnel.

Figure 10.—Photograph showing seepage from the Mogul Mine on September 15, 2015. This mine has hydraulic bulkheads to limit the outflow of water from the Sunnyside Mine.

The installation of numerous hydraulic bulkheads to flood the Sunnyside Mine resulted in drainage flows at the Red and Bonita Mine (figure 11) increasing from a minor amount to 300 gpm (Way, 2014a). Flows at the Gold King Mine Level 7 also increased; by 2005, a flow of 135 gpm was measured and, in 2006, a peak of 314 gpm was recorded. The various flow readings appear to be based on a handful of spot measurements. None of the mine drainage flows are monitored on a continuous basis.

South of the Gold King Mine are two other draining adits, the Silver Ledge Mine (figure 12) and the Blackhawk Mine (figure 13). The location of these two mine portals in relation to Gold King Mine is shown on figure 9.

Figure 11.—Photograph showing acid drainage flowing out of the Red and Bonita Mine on September 3, 2015.

Figure 12.—Photograph taken on September 15, 2015, of drainage from the Silver Ledge Mine, which is located south of the Gold King Mine.

Figure 13. Photograph taken on September 15, 2015, showing acid seepage from the Blackhawk Mine located south of the Gold King Mine.

Reclamation Activities at the Red and Bonita Mine

In 2011, EPA initiated work at the Red and Bonita Mine, which was discharging a large amount of zinc into Cement Creek. There are about 3,500 feet of underground passageways in the Red and Bonita Mine. Prior to digging open the portal, EPA contacted BOR and asked for an independent review of their plans to open the mine. The review was in the form of an hour-long telephone call where EPA described the work and BOR gave feedback. The plan was to dig open the portal and capture the water in a pond built below the waste-rock dump. BOR warned about the potential for a blowout and asked that EPA review the mine maps and calculate the volume of workings with the assumption that the mine was full of water. BOR then asked how EPA would respond to a sudden release of that much water. EPA decided to change their approach. They drilled a well about 30 feet upslope from the mine opening. It was problematic as the drill pad was unstable. The first two holes missed the adit. The third hole penetrated the mine workings, and measurements of the water level indicated that the mine had more water in it than they were expecting but it was not full to the top.

With this information, they enlarged their treatment ponds and then devised a plan to insert a “stinger” (steel pipe) through the top of the collapsed debris blocking the entrance and then pump down the water to their treatment ponds. The technique of using a “stinger” pipe had previously been used at another site in Colorado (the Golf Tunnel in 1990). Once the mine pool was pumped down, the blockage was excavated from the portal without risk of a large blowout. The adit was safely opened by October 2011.

In the next few years, the Red and Bonita Mine was cleaned out and evaluated. DRMS was providing technical advice for the EPA work at Red and Bonita Mine. They were able to access 2,000 feet of the workings beyond which there were more heavy collapses. A location for a hydraulic bulkhead was identified, rock samples were tested, and DRMS prepared a bulkhead design for EPA. In May 2015, BOR received another telephone call from EPA regarding the Red and Bonita Mine. EPA wanted an independent review of the hydraulic bulkhead plans and specifications, as well as a subsequent site visit just prior to construction. BOR received the plans and specifications in several emails in early May. Because funding from EPA to perform the review had not yet been received, a quick review was performed by BOR at the end of May, and comments were relayed via a telephone call. BOR provided the following recommendations:

- Power wash and examine the rock before pouring the concrete.
- Map any significant geologic features.
- Remove any loose soil, rock, or gouge.
- If the tunnel is not irregular, consider deepening the notch into the rock.
- Make the instrument pipe and the chemical injection pipes two different pipes.
- Put a trash rack on the upstream side of the drain pipe or perforate it so debris or a piece of timber will not clog it if they need to drain the mine pool in the future.
- Use vibrators during the concrete placement to ensure dense concrete.

Construction of the Red and Bonita Mine hydraulic bulkhead was completed in the summer of 2015. The valve at the hydraulic bulkhead was left open because EPA and DRMS believed that closing it could affect the mine pool at the nearby Gold King Mine.

Reclamation Activities at the Gold King Mine

The Gold King Mine was placed under a mining permit in 1986. This permit required that at the end of activities, the mining company close all four mine portals, and a bond was held to ensure that would be done. Most of the work was exploration.

Bond Forfeiture and Closure by the State of Colorado

After the installation of a bulkhead in the Sunnyside Mine in 1996, seepage discharge from the Gold King Mine Level 7 New Adit portal showed a significant increase. The mining company holding the permit piped acid drainage from the Gold King Mine to Gladstone and operated the water treatment facility that was formerly used to treat the American Tunnel flows. They eventually filed for bankruptcy and discontinued running the water treatment system. The DRMS imposed forfeiture of the M-1986-013 reclamation bond in 2007. That same year there was a slope failure of the Gold King Mine Level 7 waste-rock dump due to increased adit flow causing saturation of a portion of the waste-rock dump (figures 14 and 15).

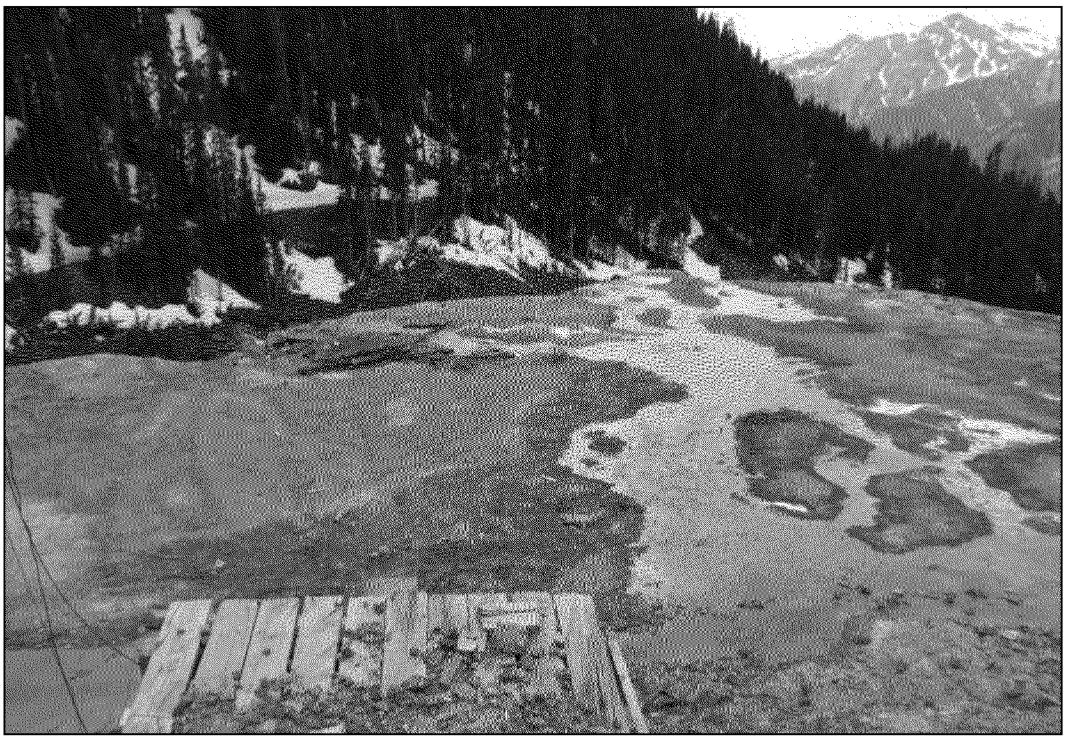


Figure 14.—Photograph showing adit seepage infiltrating into the Gold King Mine Level 7 waste-rock dump in 2007 (from DRMS project files).

Figure 15.—Photograph showing deposition of landslide material in 2007 blocking a portion of the access road near the base of the waste-rock dump (from DRMS project files).

The mine owner removed the road blockage but did not undertake any other work to maintain his property. In their Project Summary, DRMS expressed concern that water could build up behind the collapsed material at the Gold King Mine Level 7 New Adit and eventually result in a blowout. There was also concern about additional instability of the waste-rock dump.

Figure 16 shows a cross-section illustration to help interpret the photographs and descriptions provided to describe DRMS and EPA's activities at the Gold King Mine.

In 2008, DRMS rerouted the Gold King Mine drainage flow on the waste-rock dump into a lined channel, but this eventually breached. It was decided to install a larger channel made from a high density polyethylene (HDPE) pipe cut in half, thus forming a lined trough to contain the flow.

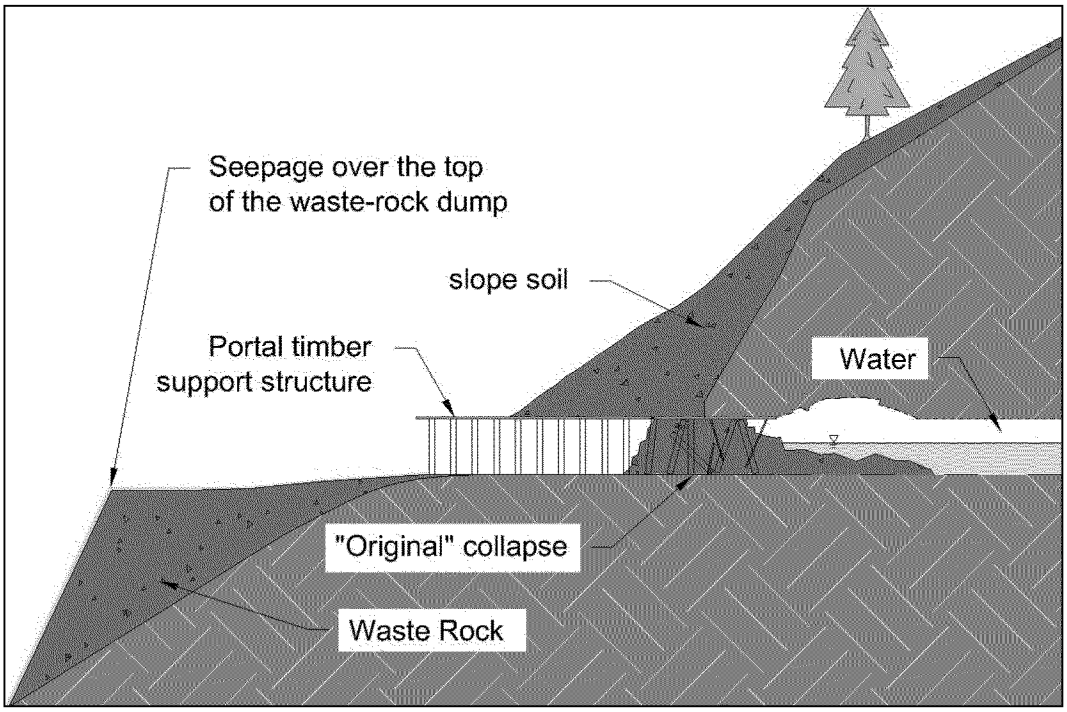


Figure 16.—Cross-section showing the condition of the Gold King Mine Level 7 New Adit in 2007 (not to scale). This shows the water level assumed by DRMS, but it may have been full of water at this time, as was later discovered.

In 2009, DRMS closed all four of the Gold King Mine portals. The Level 1 and Sampson portals located high on the mountain were backfilled. The old adit at Level 7 was backfilled from the point of the observed collapse, which was about 10 feet from the portal entrance. There was a small flow discharging from the old Level 7 adit.

The new adit at Level 7 was also blocked by debris from roof collapse. The debris was observed about 30 feet in from the portal entrance where it filled the adit up past the roof. There was about 200 gpm flowing from the new Level 7 adit. It is important to note that all references to work performed at Gold King Mine from this point forward in this report are specifically associated with the new adit at Level 7.

The DRMS installed a 2-foot-diameter turquoise drain pipe in the Gold King Mine Level 7 New Adit and a 2-foot-diameter corrugated black HDPE observation pipe above the drain (figure 17). The observation pipe included a steel grate (figure 20). The pipes were pushed into the opening until they encountered the debris from the roof collapse. More caving occurred in the adit when the observation pipe was installed. Some soil backfill was placed over the pipes to complete the installation. Neither pipe was able to penetrate the blockage and make contact with the mine pool. A perforated steel pipe (well casing) was

inserted into the drain pipe and pushed in with the backhoe bucket (figure 20). The steel pipe was unable to penetrate the collapsed material and did not make contact with the mine pool.

The water level shown in figure 16 represents the low mine pool level likely assumed by DRMS in 2009 based on their reported attempts to penetrate the blockage at the adit portal. There is no direct evidence of the actual water conditions in the mine. If the water conditions in the mine in 2009 were similar to that encountered on August 5, 2015, successful penetration of the blockage in the mine adit using the procedures attempted by DRMS might have resulted in a blowout.

Figures 17 through 20 show DRMS's 4-page project summary. The DRMS documentation contains an error; the names of the "Old Portal" and the "New Portal" are reversed in the text and figure captions. According to DRMS, they have not corrected their project documentation. The error has caused confusion among project personnel and the evaluation team when discussing the history of the mine.

Colorado Division of Reclamation, Mining & Safety

Project Summary

Gold King Bond Forfeiture M-1986-013

Phase II – 2009
Reclamation at the Sampson, Number One, and Level Seven Portals

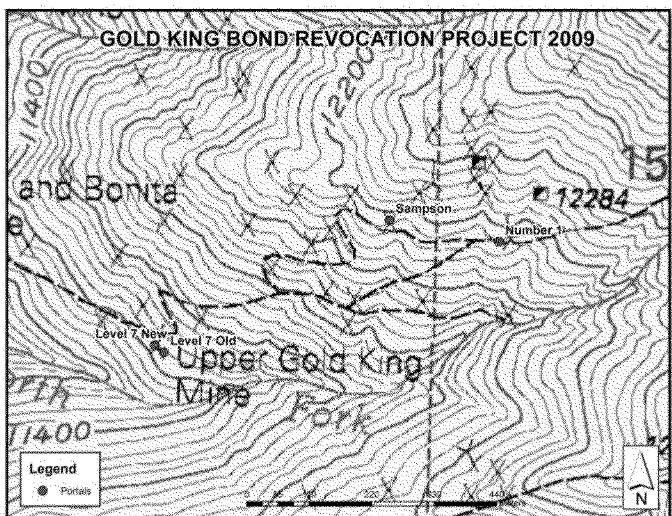
Background
The Gold King Mine has been in operation since the late 1880's. The mine continued underground mining operations through the middle of the 20th century. The M-1986-013 permit was issued to re-work three historic interconnected portals, the Level 7, Number 1, and Sampson portals. During permitted mine operations another adit was driven at the Level 7 to bypass a collapse in the original Level 7 portal. Two drill pad sites were inside the permit boundary, but were never utilized.

The three portal areas all have historic waste rock piles. During mine operations, the waste rock was re-graded to allow for better access and equipment turn-arounds. Little to no additional waste rock was added to the historic piles. Most of the newly mined excess waste rock was left underground. The high grade ore was trammed to the surface and loaded into haul trucks or temporarily stored at the surface.

All four permitted portals were originally dry because Sunnyside's American Tunnel, located downhill at Gladstone, deep-drained the mining district. In 1995 Sunnyside sealed the American Tunnel portal with a bulkhead. The result of the bulkhead was a drastic new high quantity discharge from the Gold King Level 7 portal of extremely poor quality water, making this site one of the worst draining mines in the State of Colorado.

Reclamation Plan
The Gold King Mine Reclamation Plan was bonded for backfill closure of the four portals, re-grading of the waste rock piles to 3% grade for drainage, and ripping and seeding of the road between the Sampson and Number 1 portal and a drill pad.

The reclamation plan was expanded in 2009 to include the installation of a two inch Parshall Flume to facilitate future water quality sampling by the Animas River Stakeholders Group and the current landowner. The flume was installed in the lined ditch that was previously installed under the Phase I – Gold King Permanent Portal Discharge Diversion Structure Project in 2008.



Gold King Site Map

Land Owner
Todd Hennis

Construction Contractor
K and P Property Design
236 S. 3rd #219
Montrose, CO 81401

Project Cost: $38,930.00

DRMS Project Manager
Kirstin Brown, 303.866.3567

Colorado Division of Reclamation, Mining, & Safety

Figure 17.—Page 1 DRMS 2009 Project Summary.

Colorado Division of Reclamation, Mining & Safety

Project Summary

2009 Reclamation at the Sampson, Number One, and Level Seven Portals

2009 Reclamation

In 2009 all four permitted adits were backfilled, a flume was installed in the previously lined ditch, and 1600 feet of drill road was reclaimed. The Sampson Portal was backfilled with on-site materials and the wooden and metal debris was buried on-site. The Number One Portal was also backfilled with on-site materials and the debris from the site was buried to the east of the portal in the waste pile. In addition, a 1600 foot long drill road from the Number One Portal to immediately below the Sampson waste pile was re-contoured, ripped, mulched, and seeded.

Both Level Seven portals were partially collapsed prior to backfilling in 2009. The Level Seven New Portal required additional fill to remove the unstable fifteen feet of continually collapsing timbered area that remained in front of the complete portal collapse from fifteen feet on. The Level Seven Old Portal also required additional closure in front of the complete portal collapse from thirty feet on. An observation pipe and drainage pipe were placed in the Level Seven Old Portal, but during filling around the pipes, the timbers in the portal collapsed and loose colluvial material completely covered the observation and drainage pipes. The drainage pipe continues to drain at roughly 200 gallons per minute, at the same flow rate as before the collapse. The observation pipe was meant to provide stable access to view the collapse at thirty feet, allowing the landowner and the DRMS to monitor this unstable draining adit, which is arguably one of the worst high quantity, poor water quality draining mines in the State of Colorado. Because of the collapse, DRMS decided to install a well point, driven into the collapse, through the drainage pipe, in an attempt to alleviate concerns about an unstable increase in mine pool head within the Gold King workings. The installed 6 inch perforated steel pipe penetrated approximately 12 feet of collapsed material thought to exist between the original collapse and the end of the drain pipe. The well point was unable to penetrate through any of the original existing collapse in the tunnel.

Gold King Level 7 Old Portal Closure

Gold King Level 7 Old Portal with 2" Parshall Flume Installed in Concrete Lined Ditch

Colorado Division of Reclamation, Mining, & Safety

Figure 18.—Page 2 DRMS 2009 Project Summary. The "Old" and "New" Portal labels are incorrect and should be reversed.

Colorado Division of Reclamation, Mining & Safety

Project Summary

2009 Reclamation at the Sampson, Number One, and Level Seven Portals

A flume was installed at the Level Seven Old Portal as part of the bond revocation reclamation. The two inch Parshall Flume was installed in a concrete lined ditch immediately in front of the HDPE lined ditch. The flume will be used to monitor flow by the landowner and the Animas River Stakeholders Group (ARSG).

One change order was issued on 9/17/2009 to increase the project cost by $14,980.00. There were two increases in cost to the project budget. The concrete lined ditch needed additional concrete work to make the ditch larger in order to carry the larger than estimated quantity of mine drainage for an increased cost of $12,480.00. The well point installed in the Level Seven Old Portal was also an additional cost of $2,500.00. The entire bond amount was expended on this project and the additional funding ($2,082.74) came from the State Appropriated Bond Forfeiture Severance Tax.

Number 1 Portal backfilled

Sampson Portal, Drill Road, and Number 1 Portal as viewed from access road after reclamation. Drill Road has been re-contoured and revegetated in this photo.

Colorado Division of Reclamation, Mining, & Safety

Figure 19.—Page 3 DRMS 2009 Project Summary. The text referring to the “Old Portal” is incorrect, it is actually the “New Portal.”

The mine drainage at the Gold King Level 7 Mine contains extremely high levels of metals and continues to flow between 150 and 300 gal

Colorado Division of Reclamation, Mining & Safety

Project Summary

2009 Reclamation at the Sampson, Number One, and Level Seven Portals

Remaining Reclamation Requirements

The mine drainage at the Gold King Level 7 Mine contains extremely high levels of metals and continues to flow between 150 and 300 gallons per minute. The mine drainage began after bulkheads were installed in the American Tunnel in 1995, which previously deep-drained the mining district. The mine drainage and the collapse at the Level 7 Old Portal continues to be of concern to the landowner, DRMS, and ARSG. A future project at the site may attempt to cooperatively open the Level 7 Old Portal in an effort to alleviate the potential for an unstable increase in mine pool head within the Gold King workings.

Gold King Level 7 Old Portal with well-point installed through the drain pipe. This portal may be re-opened in a future project to help stabilize the mine drainage and prevent future increases in mine pool head.

Colorado Division of Reclamation, Mining, & Safety

Figure 20.—Page 4 DRMS 2009 Project Summary. The text and caption referring to the "Old Portal" are incorrect; it is actually the "New Portal."

A concrete trough was constructed to turn the seepage flow toward the HDPE half-pipe that was previously installed. A concrete flume also was constructed to allow more accurate flow measurements (figure 21).

The DRMS stated in the project summary, “A future project at the site may attempt to cooperatively open the Level 7 Old Portal in an effort to alleviate the potential for an unstable increase in mine pool head within the Gold King workings.” Essentially, the closure did not provide adequate drainage and had the potential to blowout.

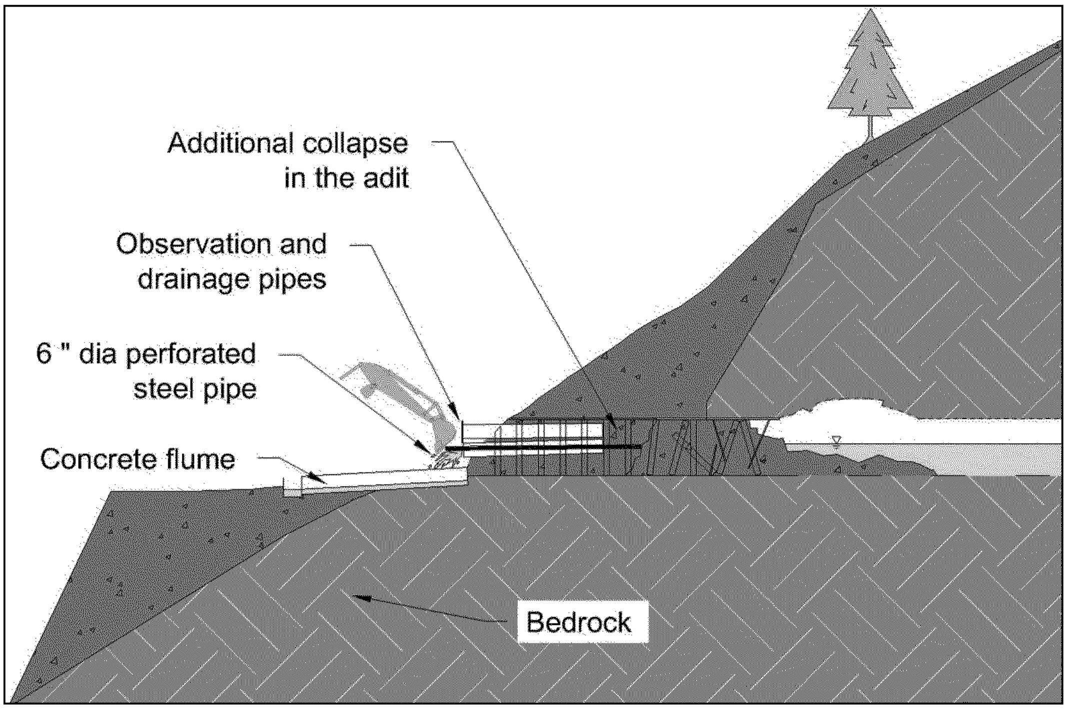


Figure 21.—Cross-section showing the installation of pipes by DRMS at the Gold King Mine Level 7 New Adit in 2009 (water level as assumed by DRMS) (not to scale).

EPA Activities in 2014

In 2014, EPA was requested by DRMS to reopen and stabilize the Gold King Mine Level 7 New Adit. The drainage system at the mine portal had reportedly not been maintained or monitored since its installation in 2009 (figures 22 through 24). During the week of August 25, 2014, the flow was measured as 112 gpm. On September 11, 2014, prior to site work, the flow had declined to less than 12.6 gpm. The reason for reduced flow was unknown but speculated as being “related to seasonal inflows to the mine” (Way, 2014a).

On September 11, 2014, excavations were performed to remove the metal grating and portions of the two pipes installed in 2009. As the excavation progressed down through the fill, seepage appeared (figures 25 through 27). The work stopped when EPA, DRMS, and others observed that in addition to the seepage from the base of the fill, additional seepage was now flowing from higher up on the face of the backfill. Because the excavation had a lip, the seepage ponded at a level equivalent in elevation to about 4 feet below the top of the adit. It was reportedly concluded by those onsite that there was 6 feet of water impounded in the mine (Way, 2014b). A small settling pond was installed at the base of the waste-rock dump to remove sediment from the mine water. The pond was not large enough to treat and settle what was believed to be 6 feet of impounded water. Therefore, the project was put on hold until the following year.

Figure 22.—Photograph showing the condition of the Gold King Level 7 New Adit portal on August 27, 2014, prior to any EPA modifications. Soil and rock debris have migrated downslope and covered a portion of the drain installed in 2009 (photograph from EPA project files).

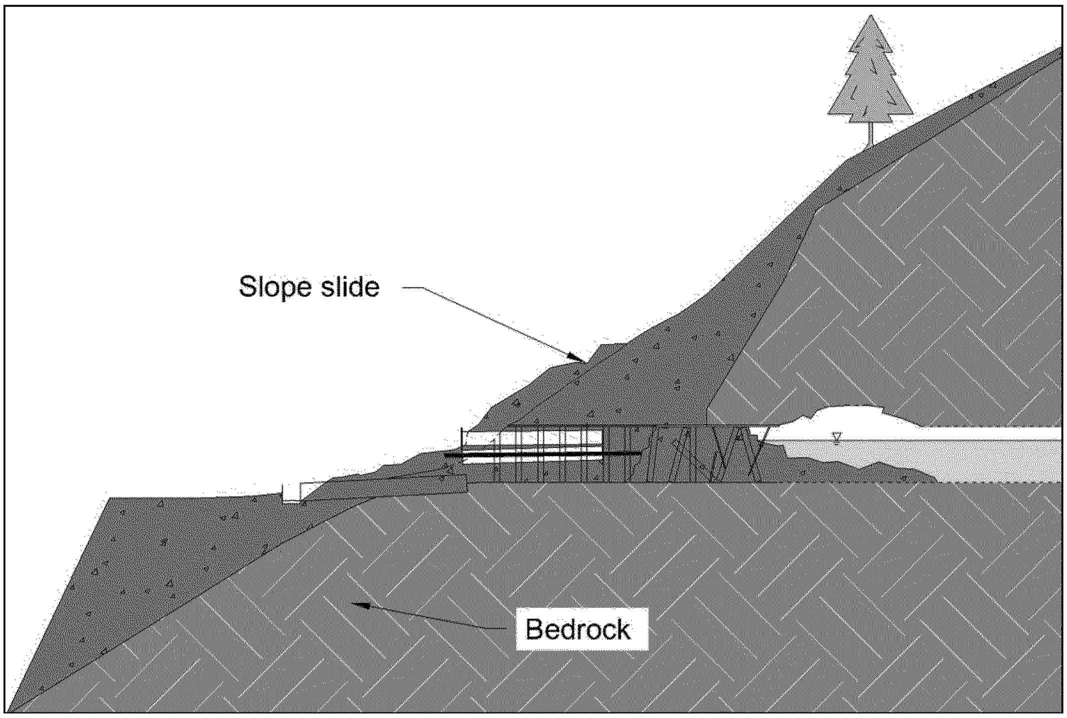


Figure 23.—Cross-section showing the condition of the Gold King Mine Level 7 New Adit in 2014 (water level as assumed by EPA and DRMS), more rock and soil had come down off the slope and were partially blocking the drain, which indicates a lack of maintenance (not to scale).

Figure 24.—Photograph showing seepage flow in the half-pipe channel at the Gold King Mine Level 7 New Adit area on September 11, 2014. Flow of approximately 12.6 gpm was recorded (photograph from EPA project files).

Figure 25.—Photograph showing excavation of the Gold King Mine New Adit portal on September 11, 2014. The metal grating and portions of the upper corrugated HDPE pipe and the lower solid-wall drain pipe have been removed (photograph from EPA project files).

Figure 26.—Photograph showing the excavation of the Gold King Mine New Adit portal on September 11, 2014, taken shortly after the photograph in figure 23 (photograph from EPA project files).

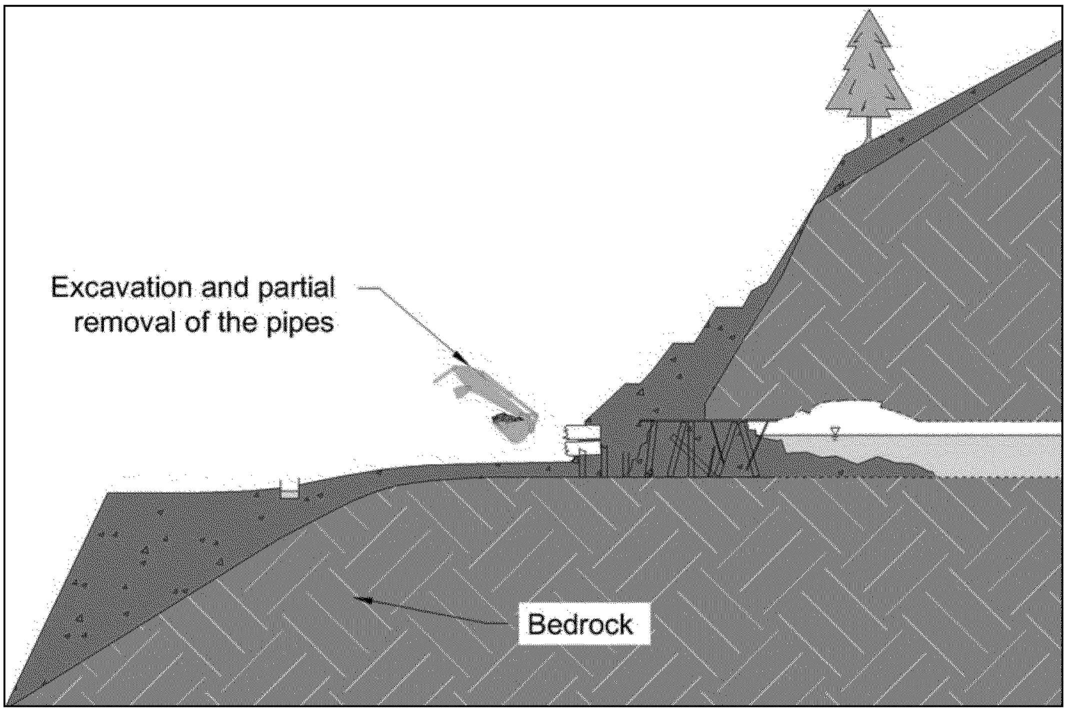


Figure 27.—Cross-section showing the condition of the Gold King Mine New Adit in 2014 (water level as assumed by EPA and DRMS) after the excavation shown in figure 23 was complete (not to scale).

Because they had torn out most of the drain and observation pipes installed by DRMS in 2009, EPA decided to install two new drain pipes surrounded by gravel and a geotextile as a temporary measure. The new pipes were laid at a different angle than the 2009 installation. The side of the concrete trough had to be cut open to accommodate the new drain pipes (figure 28).

The pipes were covered with gravel. The geotextile was wrapped around the gravel to prevent infiltration of backfill to maintain a pervious zone around the pipes. The geotextile was then covered with backfill. In order to prevent erosion of the backfill soil into the concrete trough, a layer of fast setting concrete was placed over the backfill slope adjacent to the trough (figures 29 and 30).

No work was performed at the Gold King Mine Level 7 Old Adit. The Level 7 Old Adit had only a small seepage flow as shown in figure 31. The presence of a subsidence pit in the hillside a short distance uphill from the Level 7 Old Adit portal suggested that the Level 7 Old Adit was more severely caved (figure 32).

Figure 28.—Photograph taken on September 11, 2014, showing the installation of two new 2-foot-diameter drainage pipes. An entrance slot has been cut into the concrete trough for the pipes to discharge into (photograph from EPA project files).

Figure 29.—Gold King Mine Level 7 New Adit as it appeared on September 12, 2014, when EPA completed placing backfill over the two new drain pipes. Note that a steep slope was left in place in the mountainside above the drain pipe installation (photograph from EPA project files).

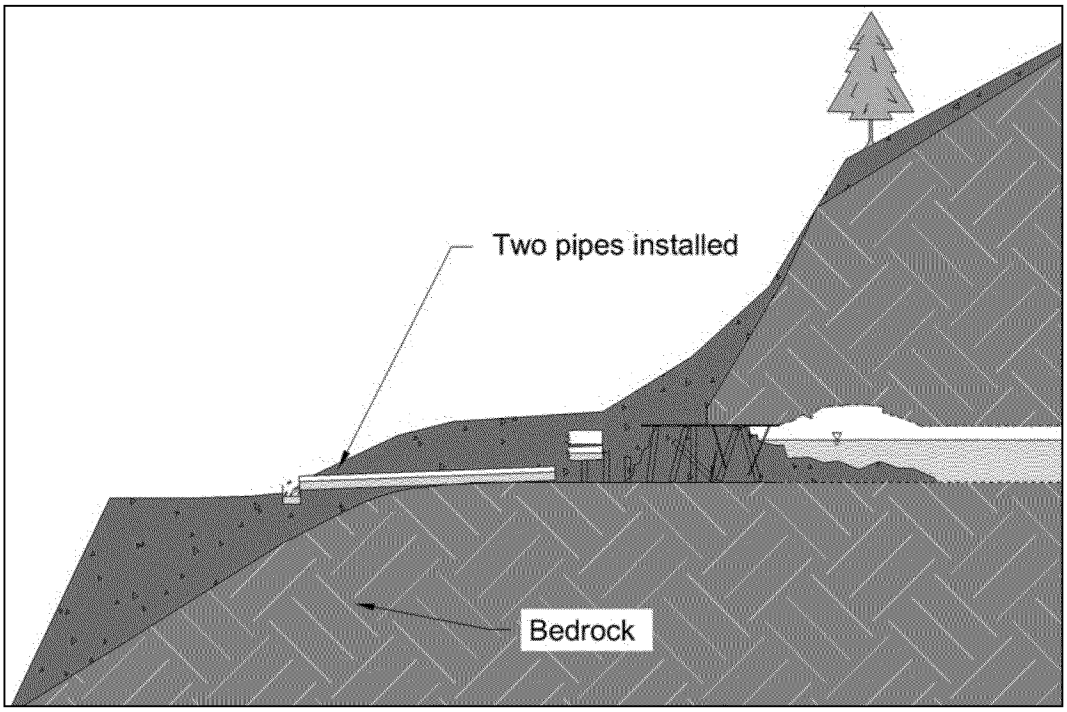


Figure 30.—Cross-section showing the condition of the Gold King Mine Level 7 New Adit in 2014 (water level as assumed by EPA and DRMS), after the installation of the two drain pipes and backfill cover (not to scale).

Figure 31.—Gold King Mine Level 7 OLD Adit (upper right) showing a small amount of seepage flow on September 11, 2014. At the portal, the floor of the old adit is approximately 2 feet higher than the floor of the old adit portal (photograph from EPA project files).

Figure 32.—Photograph taken on September 22, 2014, looking downhill at the subsidence pit located above the Gold King Mine Level 7 Old Adit.

EPA Work Activities in 2015

Personnel from EPA contractor Weston Solutions, Inc., visited the site on June 24, 2015, and measured the Gold King Mine discharge as 31 gpm. There was still snow on the ground and they had to walk in.

On July 14, 2015, EPA returned to the site and found more erosion and landsliding of the slope above the adit and that the rock and soil debris had covered the ends of the pipes they previously installed in 2014 (figures 33 through 35). Much of the adit seepage flow was bypassing the concrete-trough diversion channel and instead was flowing onto the waste-rock dump, which might cause another slide in the dump. They dug out the blockage to return all of the flow into the concrete trough (figure 33). On July 15, 2015, they took another measurement, which indicated the drainage flow was 69 gpm.

Figure 33.—Photograph showing the condition of the Gold King Mine Level 7 Old Adit portal area on July 14, 2015. Note that more soil and rock had slid from the slope area and had buried a portion of the concrete diversion channel including the ends of the two drain pipes (photograph from EPA project files).

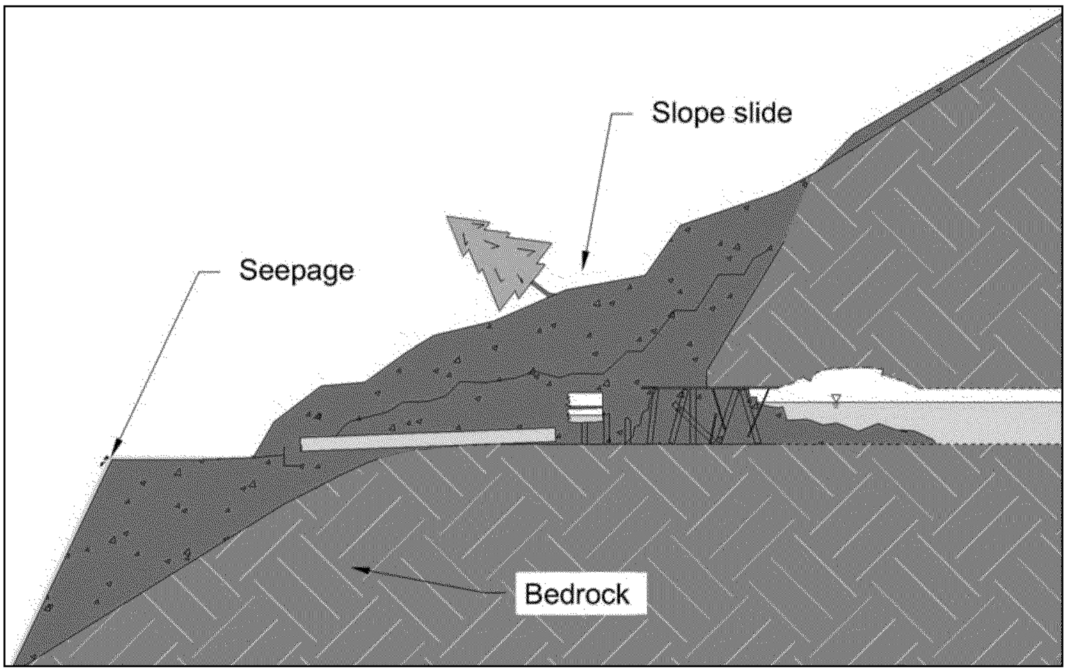


Figure 34.—Cross-section showing the condition of the Gold King Mine Old Adit on July 14, 2015 (water level as assumed by EPA and DRMS), when EPA returned to the site to begin work. More rock and soil and a tree had slid down onto the drains, and seepage was again saturating part of the waste-rock dump (not to scale).

On July 23, 2015, a plan was devised to install a shallow detention pond described as a "sump basin" on the east side of the waste-rock dump. The sump basin would be used to capture contaminated water pumped from the mine, and it would then either be run through a filter bag system to remove the iron precipitates or the water might be pumped via a new pipeline yet to be designed and installed to take it to the Red and Bonita treatment ponds. Grading activities at the waste-rock dump were begun on the following day to install the "sump," and another flow reading of 69 gpm was recorded for the adit discharge.

Figure 35.—Photograph showing the condition of the Gold King Mine Level 7 New Adit portal area on July 28, 2015. Note the soil and a tree that has slid downslope onto the portal area; at this time the seepage had been returned to the concrete trough, and the dump was drying out (photograph from EPA project files).

On or about July 23, 2015, the EPA OSC (On Scene Coordinator), who was the project leader, made a brief telephone call (about 2 minutes) to Mr. Gobla at BOR to ask if funding of $4,000 had finally been transferred to BOR for the Red and Bonita Mine. He requested that Mr. Gobla travel to the site. The EPA OSC project leader explained he was about to leave for vacation and wanted a site visit on August 14, 2015, which would be his first day back from vacation. The EPA OSC project leader stated that the upstream form for the bulkhead had been placed in the Red and Bonita Mine and they would be placing concrete in a few days. He went on to say that he did not want any more review of the Red and Bonita Mine; the purpose of the site visit on August 14, 2015, would be for the

Gold King Mine as he was "unsure about the plans for the Gold King Mine" and wanted an outside independent review of the EPA/DRMS plans by BOR. The EPA OSC project leader scheduled to have DRMS and contractor personnel in Silverton on August 14, 2015, to present the plans to BOR and be available to answer questions. This was the first time that BOR had heard of the Gold King Mine. The plan was for Mr. Gobla to travel on August 13, 2015, and be onsite all day August 14, 2015; this plan was confirmed, and the call ended without any further discussion about the project or what it would involve.

On July 29, 2015, some of the debris that had sluffed down over the winter was excavated from the portal area, and the ends of the pipes were exposed (figure 36). On July 31, 2015, work was begun putting together a manifold piping system that could be used to provide water filtration for the anticipated pump-down of the Gold King Mine.

Figure 36.—Photograph taken on July 29, 2015, showing initial excavation work at the Gold King Mine Level 7 New Adit that was performed to remove the additional accumulation of debris from the eroding slope above the adit (photograph from EPA project files).

On August 4, 2015, a representative from DRMS was onsite and viewed conditions at the adit. EPA began excavation to examine conditions close to the mine opening similar to what had been done in 2014 (figure 37).

Figure 37.—Photograph showing additional excavation at the Gold King Mine Level 7 New Adit at 10:28 a.m. August 4, 2015 (photograph from EPA project files).

Once again, they observed conditions similar to what was seen the previous year—water was seeping out at an elevation about 5 or 6 feet above the floor of the adit (figure 38).

At this juncture, EPA, DRMS, and the contractors discussed a plan to open the adit. They reportedly believed they could use a similar plan to what was done at the Red and Bonita Mine in 2011 because the seepage they were observing at that time in the excavation of the fill covering the mine portal was at an elevation corresponding to that of a partially full mine adit.

Figure 38.—Photograph showing seepage flow from the excavation at the Gold King Mine new portal at 11:48 a.m. on August 4, 2015. The flow is emerging approximately 5 to 6 feet above the floor of the adit (photograph from EPA project files).

The Plan to Open the Adit

Figure 39 shows a sketch of the plan to open the Gold King Mine Level 7 New Adit portal. To provide a margin of safety, the plan assumes the water was more than 5 feet deep on the upstream side of the blockage, but still below the adit roof.

The cross-section view from figure 39 was used as the basis for illustrating the steps that EPA was going to take to open the adit (figures 40 through 45).

A key aspect of their plan was to only excavate fill lying above the assumed top of the water inside the adit. This method would leave in place the fill holding back the water (figure 41). The next step would push a steel pipe called a “stinger” through the top of the fill to gain access to the mine pool (figures 42 and 43).

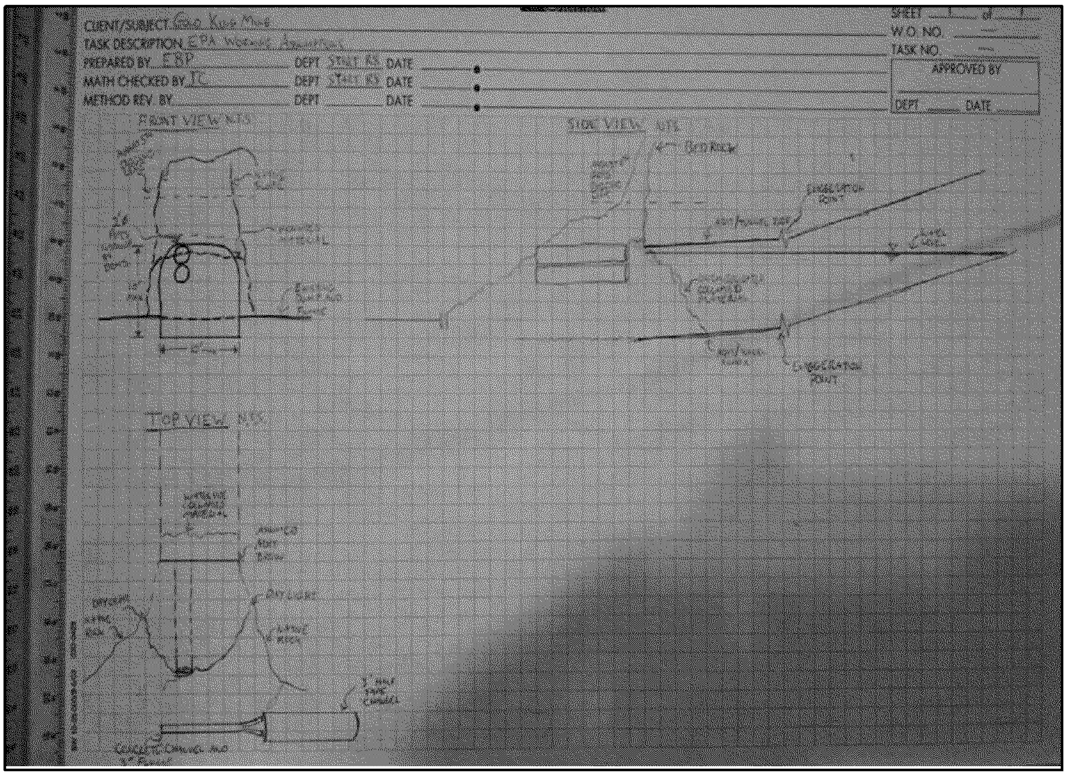


Figure 39.—Photograph showing the sketch used by EPA to illustrate the conditions at the Gold King Mine Level 7 New Adit portal (photograph from EPA project files).

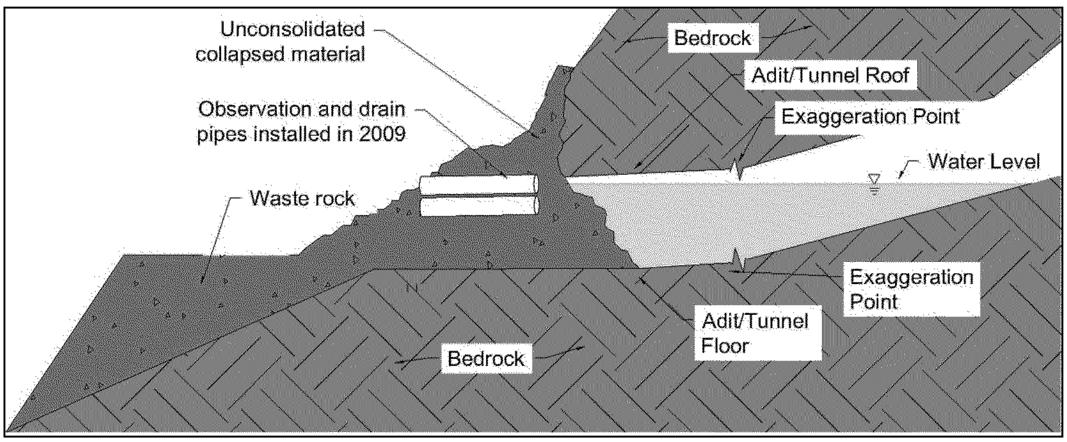


Figure 40.—Cross-section illustration showing the condition of the adit that was assumed by the EPA OSC and the abandoned mine experts from DRMS for use in planning to open the adit (not to scale). The “exaggeration point” means the right side of the drawing has an exaggerated vertical scale in order to show the 1% uphill slope of the adit. If drawn without exaggeration, the uphill slope of the adit would not be obvious on the drawing.

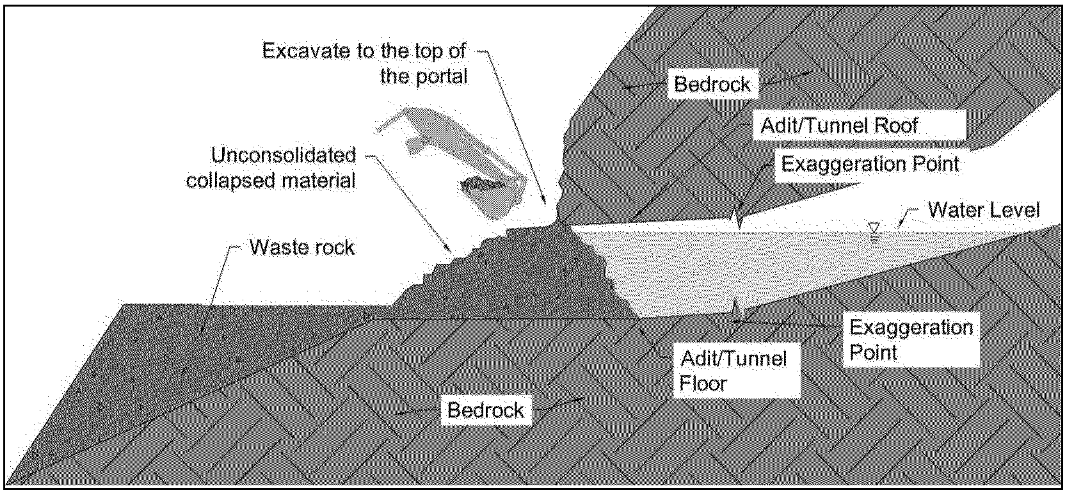


Figure 41.—Cross-section illustration showing step 1, the initial excavation to remove the drain pipes and backfill and then carefully excavate the collapsed material to expose the bedrock in the slope above the adit (not to scale).

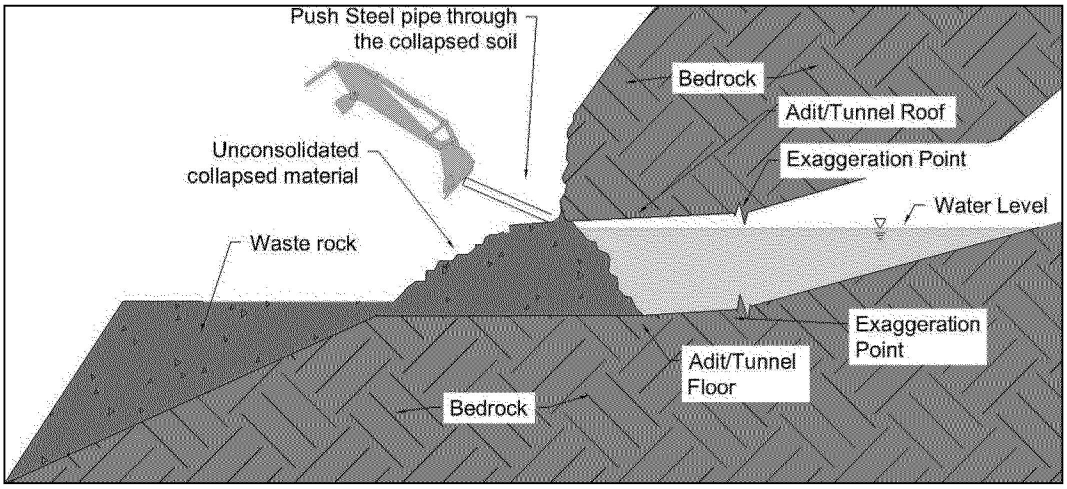


Figure 42.—Cross-section illustration showing step 2 of the plan (not to scale). With the bedrock above the crown of the adit exposed as a guide, a steel pipe called a “stinger” is positioned and pushed into the fill using the bucket of the hydraulic excavator.

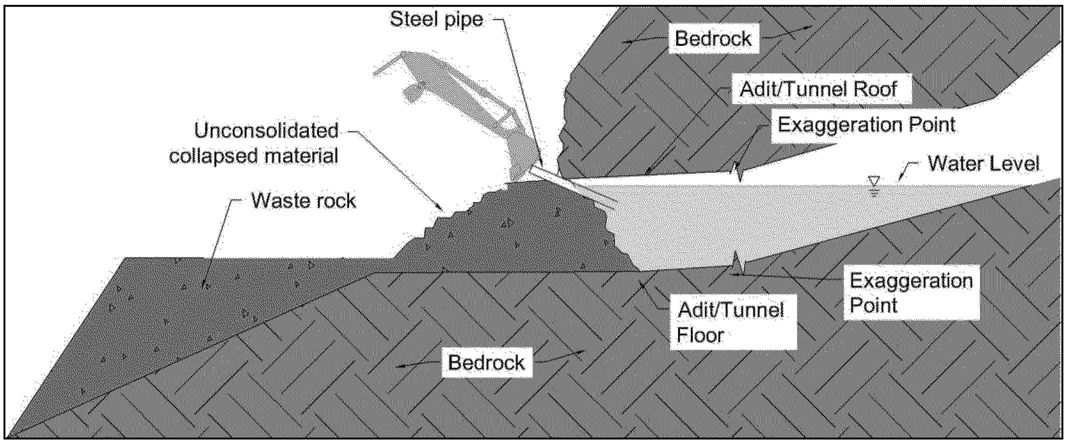


Figure 43.—Cross-section illustration showing step 3 of the plan (not to scale). With the steel pipe fully inserted, contact is made with the water impounded inside the mine.

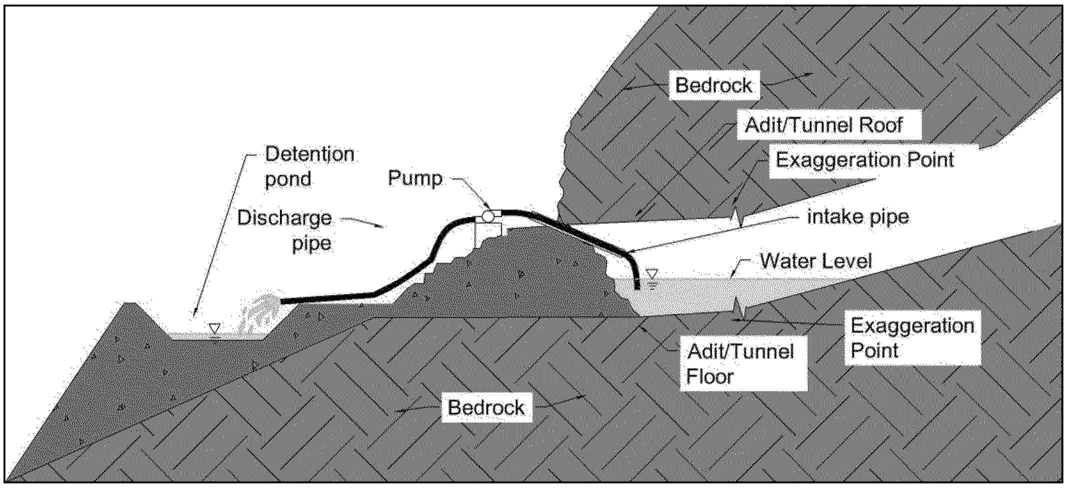


Figure 44.—Cross-section illustration showing step 4 of the plan (not to scale). An intake hose from a pump is inserted into the steel pipe. The pump discharge is taken to a small pond constructed on the waste rock dump. Water from the adit is pumped down. Not shown on this illustration is that the water in the small pond would be continuously removed by another pump and sent to treatment elsewhere on the site.

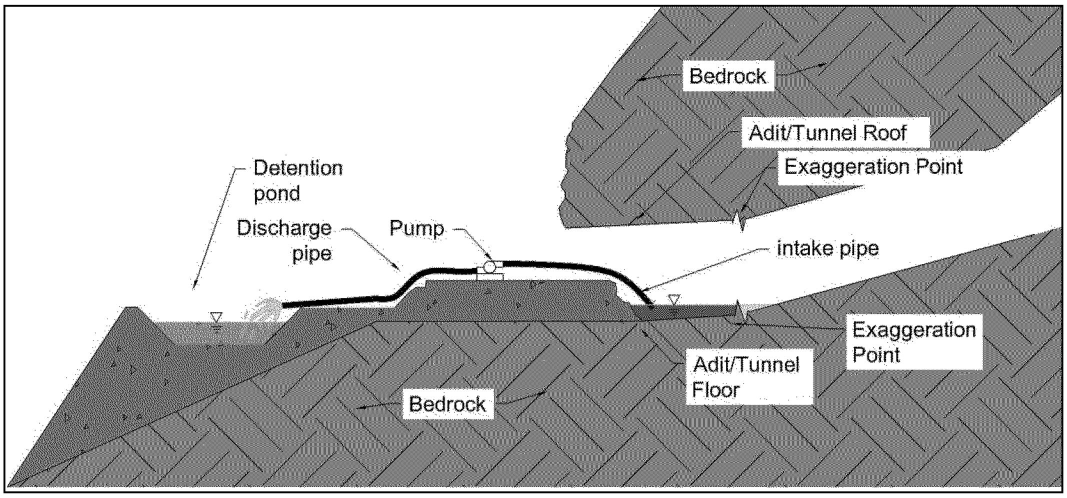


Figure 45.—Cross-section illustration showing step 5 of the plan (not to scale). As the water inside the mine is drawn down by pumping, additional fill from the blockage is excavated and the pump is repositioned to a lower level on the remaining fill. This step is repeated until all the impounded water and the remaining fill is removed; this will establish access to an open adit with the flow freely draining out.

Implementation of the Plan by EPA on August 5, 2015

On the morning of August 5, 2015, a second DRMS abandoned mine specialist arrived at the site. The two DRMS specialists joined the EPA OSC to view conditions at the Gold King Mine Level 7 New Adit. The upper seepage appeared stable and was a few feet below the top of the timbers in the excavation as shown in figure 46. In a conversation with one of the DRMS specialists, it was stated that they believed the water inside the adit was below the crown (top) of the adit for the following reasons:

- The location of the upper seepage was stable and similar to what was seen in the summer of 2014.
- No seeps or wet spots were visible higher up in the adit excavation, suggesting dry conditions behind that elevation.
- Seepage at the base of the blockage was stable at 69 gpm.
- The decrease in seepage at the base compared to previous years could be explained by seasonal variations in drainage flow.

- Only a small flow was coming out of the other (old) adit located about 100 feet away. These two adits were connected inside the mine about 970 feet back. If the mine were full, the old adit should be flowing more.

- The mine was high on the mountain, 427 feet above the Red and Bonita Mine. It was unlikely that groundwat er was high this far up on the mountain.

Figure 46.—Photograph taken at 9:15 a.m. August 5, 2015, showing the Gold King Mine Level 7 New Adit excavation uncovering mine timbers and lagging (photograph from EPA project files). Minor seepage is visible just to the left of the date stamp where a small puddle has formed. Note the soil in the upper end of the excavation above the timber lagging.

DRMS again discussed the plan to reopen the adit with the EPA OSC and were in agreement to proceed. The two DRMS specialists left the site, and the contractor began excavating (figure 47).

As the excavator continued to dig on August 5, 2015, the operator reported hitting a "spring." He stopped, they removed the excavator, and the EPA OSC went up to look at the conditions. Within moments, the "spring" began spurting upward 1.5 to 2 feet into the air (figures 48 through 50).

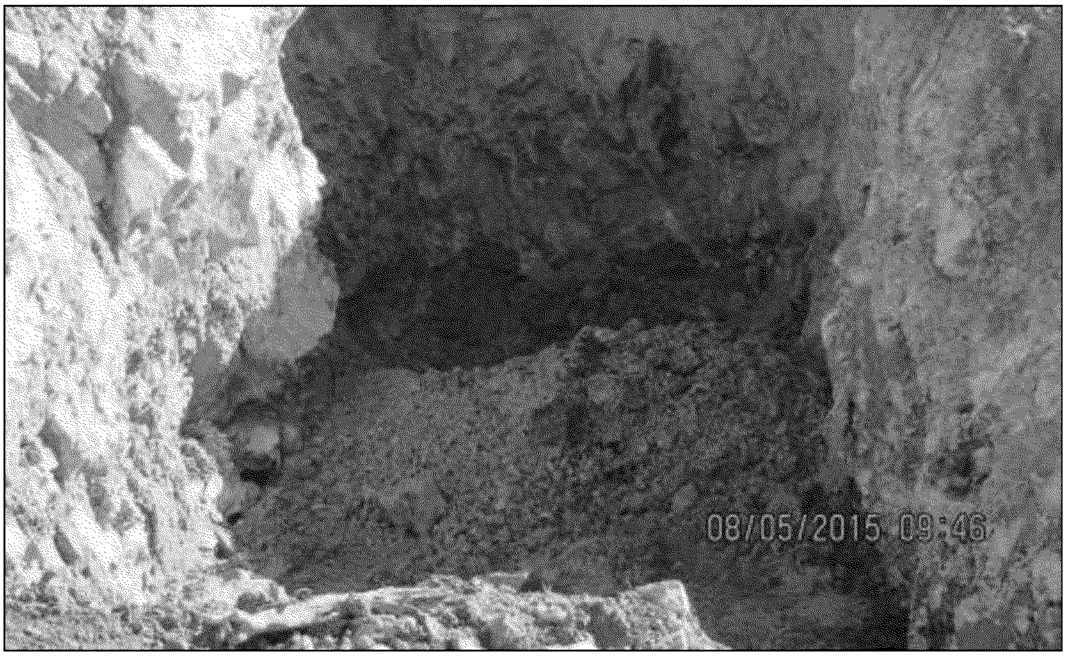


Figure 47.—Photograph taken at 9:46 a.m. August 5, 2015, showing that the loose soil from the upper end of the excavation had been removed exposing fractured and crumbly rock (photograph from EPA project files). The fill derived from the excavation had now covered the timbers, lagging, and seep visible in the previous photograph (figure 46). This indicates that the bottom of the excavation was about 10 feet above the level of the floor of the adit; this corroborates reports that they were digging high, trying to stay above the assumed water level in the adit.

Figure 48.—Photograph taken at 10:51 a.m. on August 5, 2015, showing the initial spurt of clear water (photograph from EPA project files). The center of this photograph is shown enlarged in figure 49.

Figure 49.—A cropped and enlarged version of a portion of the photograph taken at 10:51 a.m. on August 5, 2015 (figure 48). Red arrow points to the initial vertical spurt of clear water shooting up about 1.5 to 2 feet as described by the EPA OSC (photograph from EPA project files).

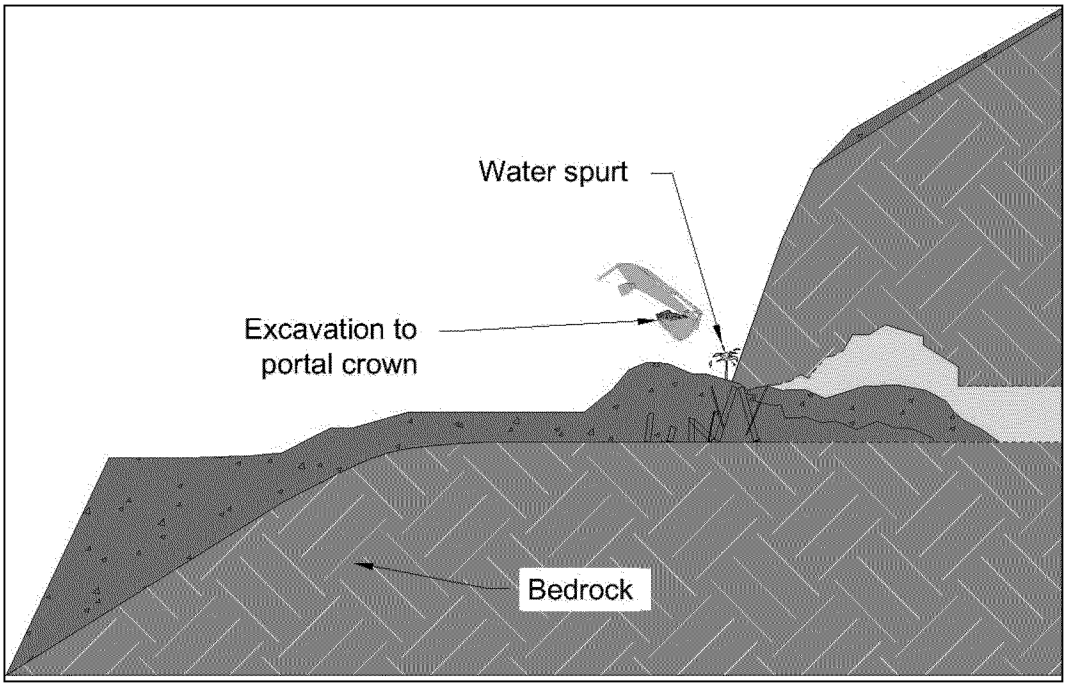


Figure 50.—Cross-section showing BOR's interpretation of the conditions immediately before the blowout as the spurt of water appeared indicating the adit was full and under pressure (not to scale).

The EPA OSC reported that the water was initially clear and then turned red; in about 3 minutes it turned orange and the flow increased rapidly. It is important to note that, in figure 50, BOR's interpretation of the water level inside the mine shows the adit full, unlike the lower water levels previously depicted based on DRMS and EPA assumptions from 2009 to the occurrence of the blowout.

Figures 51 through 59 show sequential photographs and a diagram documenting the sequence of events at the time of the uncontrolled release.

Figure 51.—Photograph of the uncontrolled flow taken at 10:54 a.m. on August 5, 2015. In 3 minutes, the flow progressed from a vertical spurt of water to the flow erosion evident in this photograph. The EPA OSC then made a decision to evacuate the portal opening to safeguard personnel onsite. A few moments later the flow erupted in an uncontrolled release (photograph from EPA project files).

Figure 52.—Photograph showing the initial blowout from the adit. At this point, the flow is surging up over the backfill that was present in the portal area (still frame extracted from a video taken on August 5, 2015, at approximately 10:55 a.m.).

Figure 53.—Photograph showing the blowout at 10:56 a.m. on August 5, 2015 (photograph from EPA project files).

Figure 54.—Photograph showing the peak outflow from the blowout. The waste-rock dump is eroding on the right side of the photograph (still frame extracted from a video taken on August 5, 2015, at approximately 10:57 a.m.).

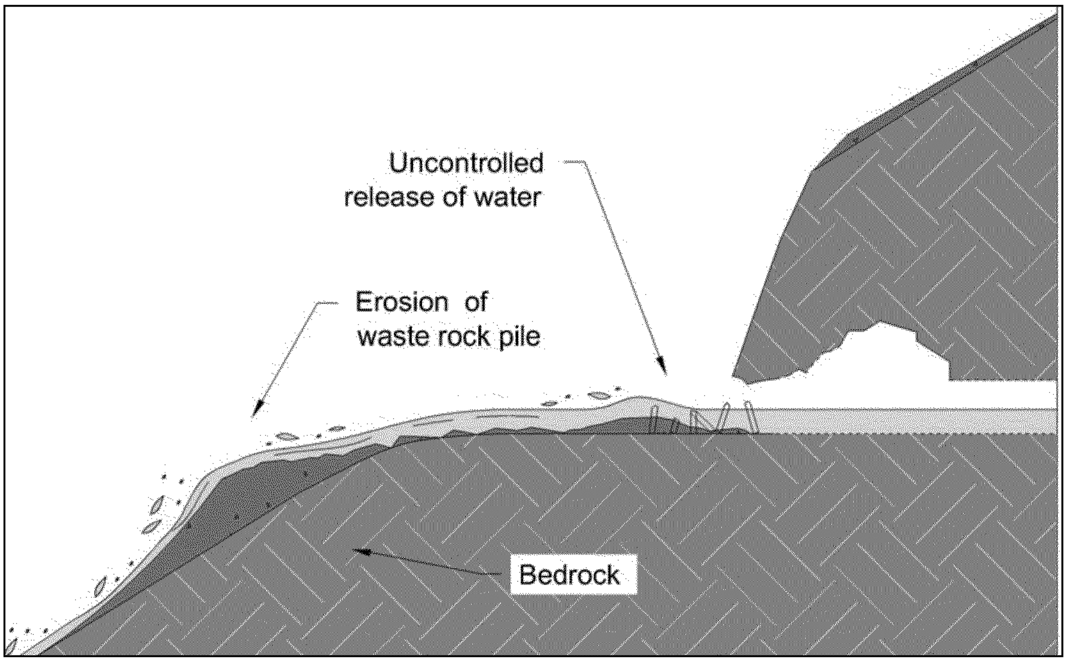


Figure 55.—Cross-section showing the blowout as it eroded the blockage and eroded fill from the waste-rock dump (not to scale).

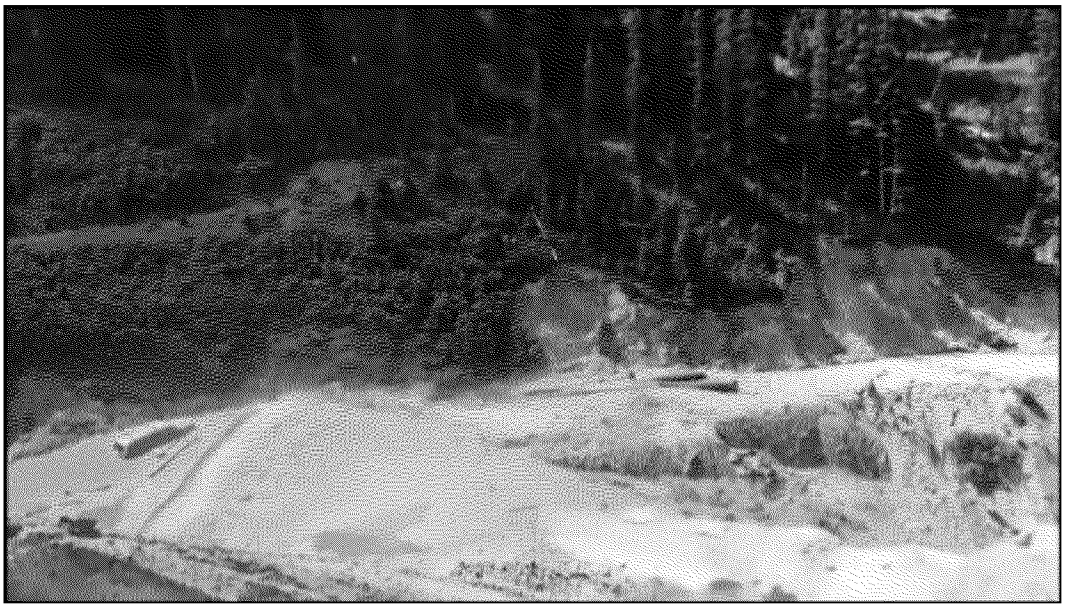


Figure 56.—Photograph showing at left, the inundation of a vehicle parked near the base of the waste-rock dump, and on the right water overwhelming the access road and cascading down into the North Fork of Cement Creek (still frame extracted from a video taken on August 5, 2015, at approximately 10:57 a.m.).

Figure 57.—Photograph showing a portion of the mine water flowing down the access road at 10:58 a.m. on August 5, 2015 (photograph from EPA project files).

Figure 58.—Photograph looking south along the lower road and Cement Creek showing the blowout flow surging across the lower road and overwhelming Cement Creek (still frame extracted from a video taken on August 5, 2015, at approximately 11:00 a.m.).

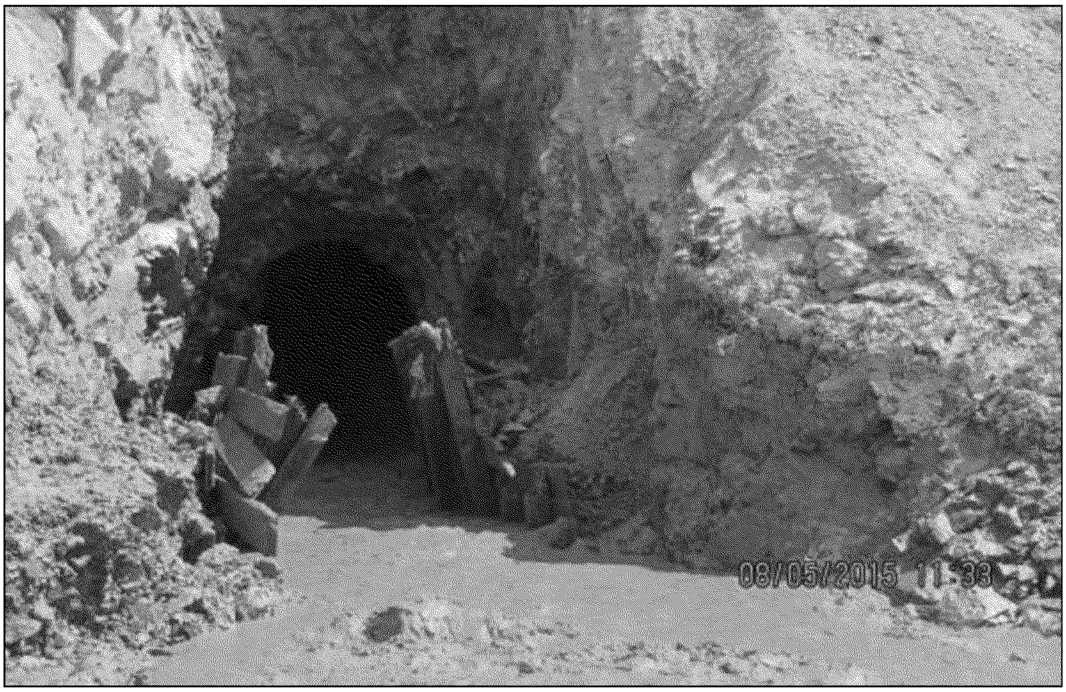


Figure 59.—Photograph showing the condition of the adit at 11:33 a.m., August 5, 2015; the peak flow of the uncontrolled release had passed and the flow rate was decreasing (photograph from EPA project files).

Actions Taken After the Release to Repair and Stabilize the Site

EPA called down for the roads to be blocked where the stream crosses them, which was promptly accomplished. They also had word passed on to people in Silverton. The details of the notifications made are not a subject of this report. At the site, the top of the waste-rock dump surface was repaired, and the flow was directed back into the remaining bit of the concrete trough and half-round pipe (figure 60). With this accomplished, all but one person left the site by walking down the mountain. One person stayed behind for a few hours to monitor the adit for additional outbursts.

After notifications were initiated, work began on road repair to reestablish access to the site. This work continued into mid-September. Most of the debris had been deposited in Cement Creek near the confluence with the North Fork of Cement Creek. The debris was removed. Temporary water treatment ponds were constructed on the North Fork using the debris (figure 61). The ponds were immediately put into operation.

Figure 60.—Photograph showing that the flow had been routed back toward the half-round pipe by 12:06 p.m. on August 5, 2015 (photograph from EPA Project Files).

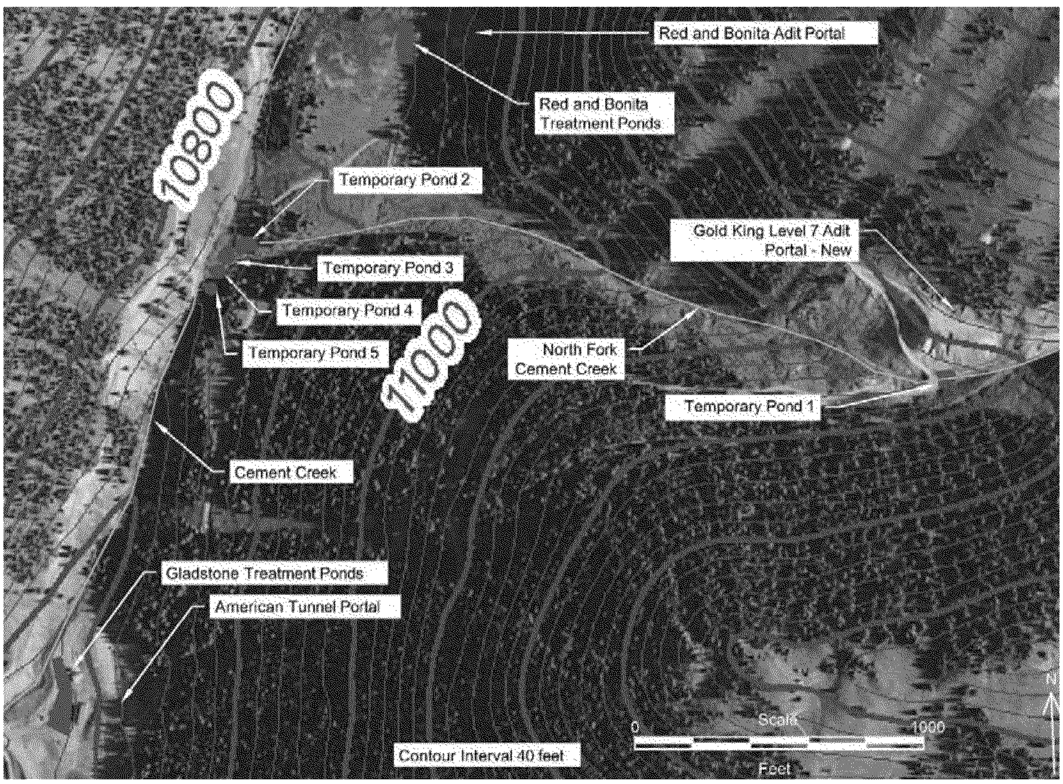


Figure 61.—Illustration showing the location of the temporary treatment ponds that were placed on the North Fork of Cement Creek after the incident.

The EPA initially began adding sodium hydroxide to neutralize the continuing mine flow, which was now at 600 gpm. They switched the water treatment chemical to lime a few weeks later to avoid the sodium loading that was resulting from the use of sodium hydroxide. A polymer was used to improve sludge precipitation.

The treatment ponds are in a location where they will not survive the following winter and spring snowmelt. Construction was begun on ponds at Gladstone and piping of water to the Red and Bonita ponds and the new ponds at Gladstone. Once complete, EPA removed the ponds from the North Fork of Cement Creek.

With the water treatment system in place, EPA initiated work to stabilize the mine opening. After removing the mine timbers (figure 62), a drain pipe was installed as far back as possible. This was a temporary measure to guard against the weak mine rock from caving in and blocking the drainage. Because a roof collapse would fall with great force, it could crush the 24-inch outside-diameter drain pipe, and so a stronger 8-inch inside-diameter thick-walled HDPE pipe was placed inside of it as shown in figure 63.

Figure 62.—Photograph showing the Gold King Mine Level 7 New Adit on August 16, 2015, after an excavator was used to reach inside the mine opening and remove the timbers. Note piles of debris from partial roof collapses inside the adit.

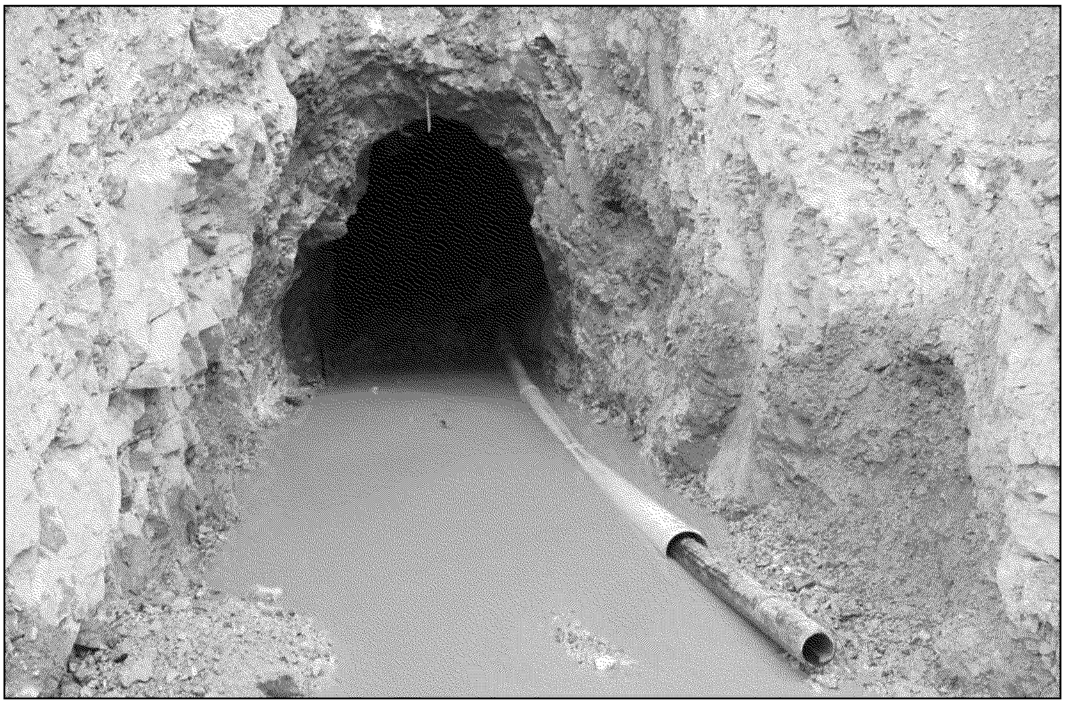


Figure 63.—Photograph showing the adit on August 16, 2015, with an 80-ft long (four 20-foot segments) turquoise-colored 24-inch outside-diameter drain pipe inserted into the adit opening. An 8-inch inside-diameter black HDPE pipe has been inserted into the 24-inch diameter pipe.

The sides and the rock face above the adit were dug out in preparation for rock bolting (figure 64). The operator reported that the digging was easy because of the fracturing and clay in the altered rock.

By September 15, 2015, the outside rock surfaces had been strengthened by rock bolts and wire mesh (figure 65). The stabilization operations progressed to inside the mine. Two 24-inch diameter buried pipes were installed to carry water out of the adit.

The next steps will be to shotcrete the entrance and install steel sets underground. The large dome-shaped collapsed areas inside the mine entrance will be supported with steel sets and be filled. Once complete, the portal will be stable. Installation of some type of flow limiter at the portal in case there is a blowout deep inside the mine is under consideration.

Figure 64.—Photograph showing the adit on September 3, 2015, at the initiation of rock bolting. The rock had been excavated to provide a larger work area. Note the excavator teeth marks left in the rock, an indication that the rock is altered and contains a significant amount of clay.

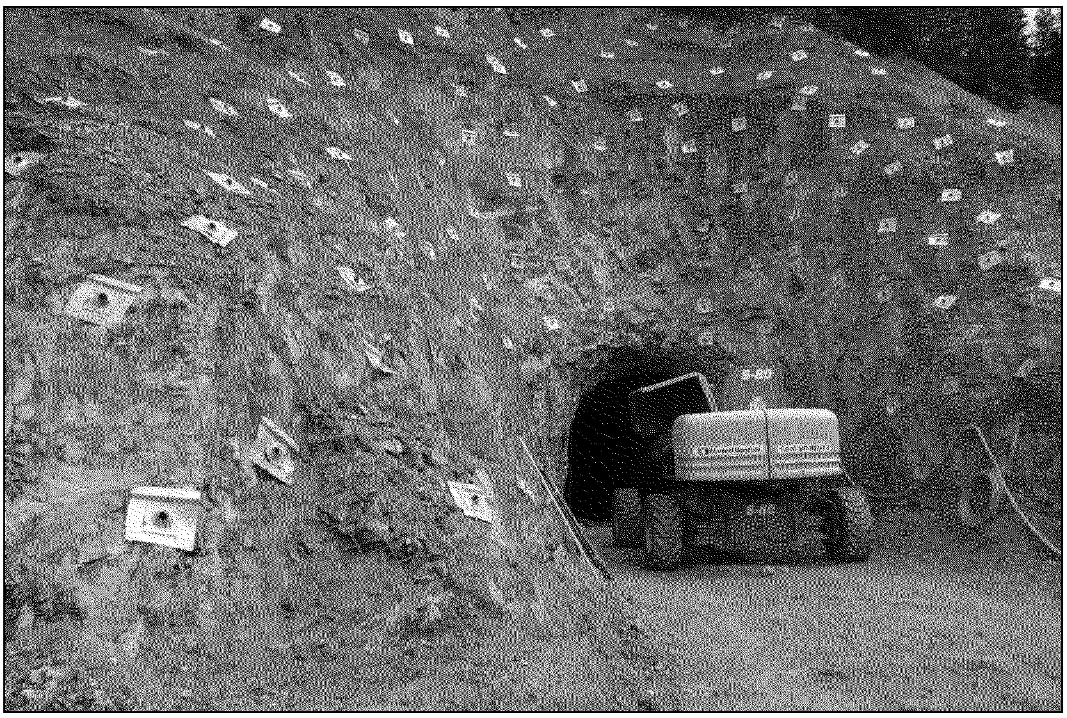


Figure 65.—Photograph taken on September 15, 2015, showing the installation of wire mesh and rock bolts to stabilize the outside of the mine opening.

Engineering Analysis

A cursory engineering analysis of the incident was performed by the evaluation team to examine potential failure modes, extent of the mine pool as it relates to the water pressure at the plug and the volume of discharge as a consequence of plug failure, likely soil properties and the effect on flow through the backfill plug, and stability of the backfill plug.

Potential Failure Modes

Mine blowout incidents have occurred due to numerous causes (table 1). In the case of a mine, where water is being held back by a blockage formed by collapse of the roof or by backfill, there are five potential failure modes that could occur:

- Internal Erosion (Piping) – Seepage through the blockage begins to remove soil particles from the soil, the seepage flow rate increases removing more soil, eventually a direct flow pathway is opened from the mine pool to the downstream side of the blockage, and the flow increases rapidly. The increased flow rapidly erodes more soil creating a large opening through the blockage resulting in an uncontrolled release of water from the mine.

- Instability – Rising water behind the blockage builds up pressure against the blockage. The pressure eventually exceeds the shear strength of the blockage pushing it down the passageway and out of the mine entrance allowing an uncontrolled release of the water.

- Heave (uplift) – Water pressure within the adit heaves the material overlying the portal allowing flow out of the portal.

- Overtopping – A partial collapse of material does not completely fill the mine passage to the roof. Water accumulates behind the blockage forming a reservoir that rises in elevation. When the water reaches the top of the blockage it flows over it to the downstream side. The soil is eroded by the overtopping flow, and the remaining reservoir of accumulated water is released from the mine in an uncontrolled manner.

- Excavation Induced Failure – While attempting to open a blocked mine the seepage pathway is shortened and one of the previous failure modes is triggered.

The failure mode associated with the Gold King Mine Incident was an excavation induced failure that triggered internal erosion.

Table 1.—Causes of Mine Blowouts

Cause of Blowout	Examples: Date and Location (see Appendix A for details)
Collapse of abandoned mine roof causes a rapid buildup of water pressure that overwhelms the debris pile	1995 – Dominion Coal Company Mine at Big Stone Gap, Virginia 2008 – Golden Anchor Mine, Powell County, Montana
Attempt to locate and open a seeping abandoned mine opening that was incorrectly believed to have very little impounded water was excavated causing a blowout	2007 – Shawmut No. 33 coal Mine, Elk County, Pennsylvania
Extreme precipitation causes flooding that rapidly fills abandoned mine workings and results in a blowout	2003 – Burlington Mine, Jamestown, Boulder County, Colorado
Improper design of hydraulic bulkhead causes failure of the adjacent rock surrounding the structure	1994 – Chandler Adit, Summitville Mine, Rio Grande County, Colorado
Mining too close to flooded mine workings or subsurface watercourse	1943 – Argo Tunnel, Idaho Springs, Clear Creek County, Colorado
A waste impoundment constructed over an abandoned mine caused the mine roof to fail. Rapid inundation of the mine was followed by blowout	1996 – Arch Mineral Corp. Mine, Lee County, Virginia 1996 – Buchanan No. 1 Mine, Oakwood, Buchanan County, Virginia
A coal barrier pillar left in place along the outcrop failed due to hydraulic pressure from an overlying coal waste impoundment, which rapidly inundated the mine followed by blowout	2000 – Martin County Coal Corporation Mine, Inez, Martin County, Kentucky
Mining too close to surface body of water caused rapid inrush followed by blowout	1978 – Sunnyside Mine, San Juan County, Colorado
Installation of hydraulic bulkhead caused pressure against a thin layer of soil and rock elsewhere on the mountainside resulting in a blowout	1992 – Keystone Mine, Shasta County, California 2009 – Coal mine at East Bank, West Virginia

Extent of the Mine Pool

The EPA project team assumed that the adit was not full to the top with water based on visual observations made on September 11, 2014, and again on August 4 and August 5, 2015. The indirect evidence about the water level in the mine appeared persuasive, and the prospect of drilling into the mine from above was far more challenging than at Red and Bonita. Water from the adit was flowing through the lower portion of the backfill at a rate of 69 gpm giving the impression that there was a free flowing system and that water was not rising in the mine pool.

Records indicate, however, that the flow increased from 150 to 300 gpm in the years prior to the 2009 closure; flow was 200 gpm during the 2009 closure, 112 gpm in August 2014, and 69 gpm in August 2015. The reduced flow was apparently judged to be attributable to seasonal variation. Although there is some

evidence of seasonal variation, the flows are not continuously monitored. With only a few measurements taken each summer and fall, the pattern of seasonal variation of the flow could not be known with any certainty.

The adit was thought to be 10 feet tall, but after the blowout the support timbers were measured and found to be 8 feet tall; thus, the crown of the adit at the portal area was slightly higher than 8 feet because of thickness of the lagging. In early October 2015, the portal was stabilized. EPA made a partial mine entry. It revealed that about 55 feet inside there is no more evidence of roof collapse, and the adit opening narrows to a 6-foot wide by 7-foot tall passageway. BOR evaluated the available volume of workings in the Gold King Mine Level 7 using mine maps obtained from DRMS (figure 66). Some assumptions must be made about the exact dimensions of the new and old adits, how connected they were depending on collapses inside the mine, and the possibility of other collapses preventing some of the passageways from filling with water. The Level 7 adit slopes upward away from the portal at an approximately 1% grade. Analysis indicated that three million gallons would have filled the total volume of Level 7 from one-half full to two-thirds full depending on the extent of passages that were blocked off or were smaller than assumed. The larger number is more likely correct because the 3-million-gallon release could not have come from a portion of the old adit. The new and old adits connect 970 feet inside the mine where the floor elevation is about 10 feet higher than the portal. Even if the old adit were full, only about one-half of the water could have flowed toward the intersection of the two adits because of the slope of adit floor. About half of the water in the old adit would remain trapped and could not have contributed to the 3-million-gallon release.

More importantly, because of the gently inclined slope of the new adit to provide drainage, even if the 3 million gallons did not completely fill Level 7 of the mine, it would have completely filled the mine portal area under pressure. The floor of the adit 1,000 feet back in the mine is 10 feet higher than it is at the mine entrance. Even if the water was only 1 foot deep there, the pressure against the portal blockage would have been equivalent to 11 feet of water. The Level 7 adit is estimated to be approximately 2,400 feet long, and therefore it can reasonably be assumed that the water pressure at the portal was significantly higher than that resulting from the water being simply full to the roof at the portal.

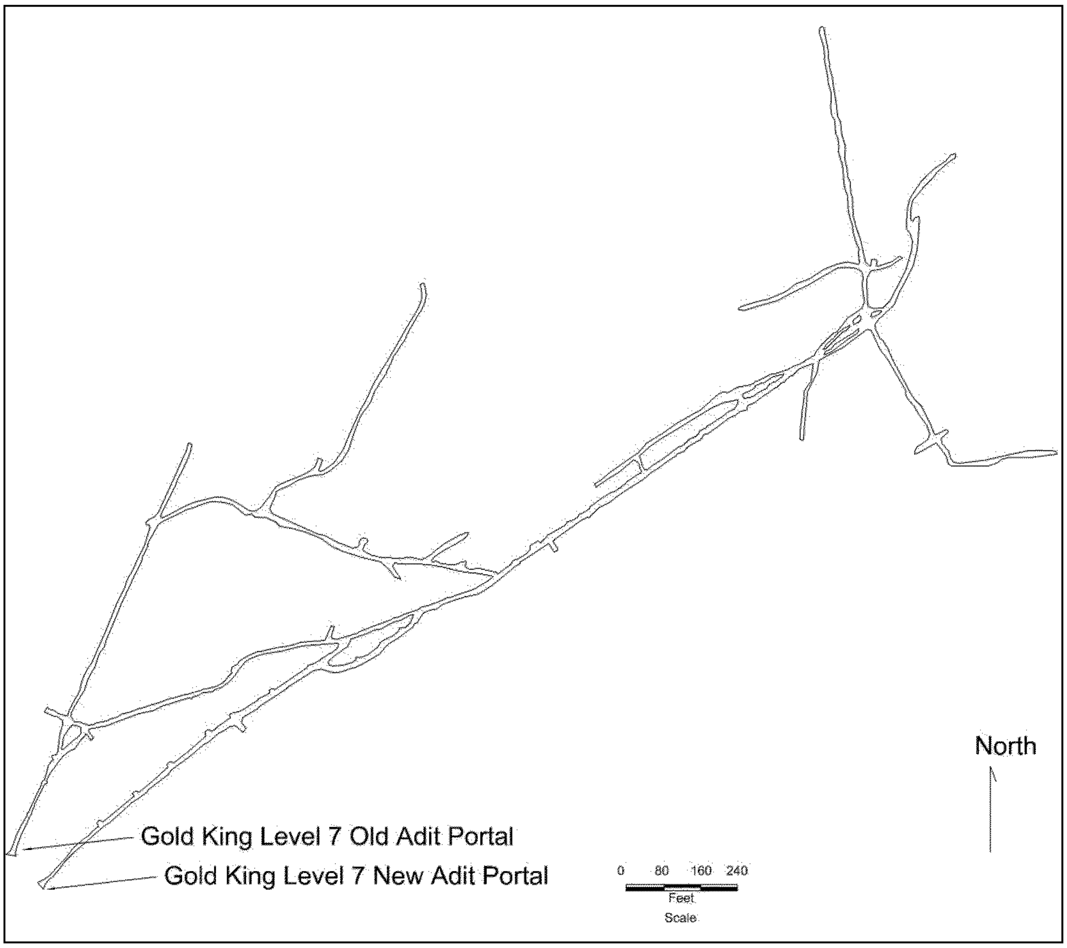


Figure 66.—Map showing the extent of the Gold King Mine Level 7 underground workings.

Evidence for Flow Attenuation

The assumption that the adit was not full of water was apparently primarily based on excavations made into the downstream side of the backfill at the portal where seepage was visible at a level that was approximately 5 to 6 feet above the floor of the adit. The EPA project team incorrectly concluded that the water level inside the mine was at the same or a slightly higher level than the outside seepage; thus, the pool of water inside the mine would be a few feet below the top of the adit roof.

Two samples of the soil from the site were tested (appendix C). Both samples were classified as GC (clayey gravel with sand) with PI (plastic index) values of 13 and 14. Two samples of the clayey gravel were tested for permeability with results of 3.6×10^{-3} cm/s and 3.4×10^{-4} cm/s. This material is not free draining with respect to the observed seepage quantities

An additional factor is the accumulation of iron-oxyhydroxide sediment in the mine. This sediment is notorious for plugging abandoned mine openings and drainage pipes. In one case, an abandoned mine drain became plugged with sediment resulting in blowout of the adit (Wolkersdorfer, 2008). The accumulating layers of sediment on the upstream side of the blockage at the Gold King Mine could have reduced its permeability over time and likely contributed to the declining seepage outflows from the mine.

Potential for Failure of the Earth "Plug"

Not only did the observations about the seepage from the mine not take into account that the debris plug contained a significant amount of clay that would attenuate the flow; the debris also had both cohesive strength from the clay and frictional strength from the sand and gravel content. The blockage, which was a combination of collapsed debris and loosely placed backfill, essentially formed an earth "plug" that was strong enough to resist water pressures. Because the length of the blockage is unknown, and the actual soil was washed away by the incident, it is not possible to calculate the precise amount of pressure that it could have held. Even a short blockage composed of a GC soil would have been able to resist some pressure. Obviously, the events of August 5, 2015, showed this to be true because the initial sign of trouble was a spurt of water into the air (evidence of pressure).

The earth "plug" was not an engineered structure and thus was not constructed in a controlled manner. It was a combination of collapsed debris within the mine, backfill placed by dumping from the bucket of an excavator, and material from surficial slope failure at the mine portal. In addition, the clay content of the soil was sufficient to give the "plug" some resistance to internal erosion. With the passage of time, the continued sediment buildup would have made the "plug" even less able to transmit seepage flow. Eventually, even if no action had been taken, it may have failed on its own. In retrospect, there was a potential for a failure in 2009 when DRMS tried to penetrate the blockage at the portal with a steel pipe. The adit flows were already in decline, and our analysis of the mine map geometry has shown that the mine pool was likely already at the top of the adit at that time. The insertion of steel pipe might have initiated internal erosion along its perimeter had it penetrated into the mine pool.

On August 5, 2015, the excavation by EPA shortened the seepage pathway through the soil. The spurt of water under pressure quickly changed in color, and the flow increased in volume. The pressurized flow had sufficient velocity to initiate internal erosion of the soil. The continued flow erosion rapidly enlarged the flow pathway resulting in the uncontrolled release of mine water. It is concluded that the failure mode was an excavation induced failure. The excavation shortened the seepage pathway through the soil initiating an internal erosion failure.

The Current State of Practice in Abandoned Mine Remediation

As part of the technical evaluation of the Gold King Incident, the evaluation team found it useful to assemble a brief history of mining incidents in the United States and the responses to these incidents in terms of the development of standards of practice. This current state of practice in abandoned mine remediation, both locally and nationally, forms a lens through which the Gold King Mine incident can be viewed.

Many uncontrolled releases of mine water have occurred in the United States. Most of these releases have not been documented or have received only brief attention in a local newspaper. Appendix A presents information about incidents for which documentation was readily obtained. Although it includes most major incidents, it is not a comprehensive list.

Water-impounding bulkheads (plugs) have been installed in many mines in the United States. By 1910, the construction of concrete bulkheads was a common practice in the United States as a means to prevent inflow of water into underground mines to protect mine workers. About 60 years later, the same technology of hydraulic bulkheads began to be used to prevent water from flowing out of underground mines. Appendix B presents readily available information about bulkheads installed in the past 25 years to contain water inside underground mines. It is not a comprehensive list.

Written mine safety regulations that active mining operations must follow have evolved as the result of numerous catastrophic releases of mine water. These regulations are administered by (1) the Mine Safety and Health Administration (MSHA) for active mines, but not abandoned mines, (2) the Office of Surface Mining for coal mines, and (3) various State mine inspector organizations throughout the country for active mines. Prior to excavation near impounded water in flooded abandoned mine workings, a mining company is required to ascertain the location and extent of the water (by review of mine maps, geophysical methods, or preferably by direct observation through boreholes) and determine safety measures necessary to protect against a sudden inflow into the excavation. However, experience in the mining industry shows that even having strict rules in place does not prevent all blowout type of failures. The incidence of blowouts at active operating mines has been reduced but not eliminated.

A disastrous underground mine inundation event in 1895 in Colorado led to the establishment of a requirement that prior to excavation near flooded mine workings, the mining company must determine the nature and extent of the impounded water (by drilling or other means) and devise plans for safely removing or avoiding the water including probing ahead with long drill holes.

After other similar events in Michigan, New Jersey, and elsewhere, it became a federal mine safety regulation for operating mines. There is no equivalent mandatory requirement for the reopening of abandoned mines.

The danger and need to guard against blowout is rarely mentioned in abandoned mine technical manuals, design guides, or project documents. Some handbooks issued by EPA provide some guidance about abandoned mine work; one briefly mentions drilling into abandoned mines (Scott and Hays, 1975), another is more typically focused on environmental aspects of the work such as sampling, waste characterization, and water treatment (U.S. Environmental Protection Agency, 2000). Neither of these EPA documents are actual requirements that must be followed.

Contact was made with three states and the Bureau of Land Management. According to the Colorado DRMS, they do not have a written policy on this. They do have a presentation that is provided to new employees about abandoned mine work that mentions the possibility of a blowout and precautions to take such as drilling to evaluate the mine pool. Telephone calls to California and Idaho revealed that their abandoned mine programs do not have any written requirements or guidelines regarding the reopening of abandoned mines or the need to evaluate the mine to guard against blowout. The Bureau of Land Management also reported that they do not have specific written requirements for opening an abandoned mine.

Establishment of Abandoned Mine Reclamation Programs

In the 1970s, many States began passing mine reclamation laws in response to the growing problems associated with coal mines. Large surface coal mines had created unsightly areas of eroding waste banks, while caving underground mines led to the formation of subsidence pits and sinkholes affecting roads and buildings. Both surface and underground coal mines were creating ever increasing miles of polluted streams due to acid mine drainage and soil erosion. One incident in particular demanded a National response.

At Buffalo Creek, West Virginia on February 26, 1972, Pittston Coal Company's coal slurry impoundment dam #3 failed during heavy rains. The failure cascaded down the stream valley causing other impoundments located immediately below also to fail. An estimated 132 million gallons of liquefied coal mine waste created a flood wave killing 125 people, destroying more than 500 homes, and causing other damage. In response to this tragedy, the Congress passed the Surface Mining Control and Reclamation Act (SMCRA) enacted August 3, 1977. The act resulted in the creation of the Office of Surface Mining Reclamation and Enforcement (OSMRE), which established a permitting process for coal mines including professional engineering design and review for coal mine dams and

waste impoundments. The act also established an Abandoned Mine Land Reclamation Program. The program included provisions to collect fees on coal production and apply portions of those fees to reclaim land and waters damaged by coal mining prior to the law's passage. An important part of this work was the establishment of a National Mine Map Repository and an Abandoned Mine Land Inventory System. The inventory system was developed as a means of identifying problems with abandoned mines, prioritizing funding for abandoned mine reclamation, and recording information about mines that have been reclaimed. Under SMCRA, more than $10 billion in taxes have been collected and hundreds of abandoned mine sites have been remediated. In states where the coal mine problems have been dealt with, the funds can be used on mines other than coal such as hard-rock metal mines. For example, Colorado gets about $2 million per year from the fund, and most of the money is applied to non-coal mine sites. One aspect of SMCRA is that there are coal states and non-coal states. States without coal production do not qualify for SMCRA funds.

In Colorado, the Open Cut Land Reclamation Act was established in 1969 followed by the Open Mining Land Reclamation Act of 1973; both of these laws exempted metal mines. The Colorado Mined Land Reclamation Act was enacted in 1976 and it applied to all mines in the State. Similar actions were taken in other states as society recognized that the physical safety hazards such as open mine shafts and the environmental effects from eroding mine wastes and acid mine drainage were no longer acceptable byproducts of metal mining. Similar to what occurred with coal, during the 1980s and continuing to the present, Federal and State agencies implemented the inventorying of non-coal abandoned mines to identify problem sites and to request funding for reclamation.

By the early 1990s, as the initial inventory results were reviewed, it was realized that the Nation faced a huge challenge in dealing with its historic abandoned mines. Abandoned mines are a form of decaying infrastructure. Unlike an old dam or bridge, an old mine no longer provides a benefit to society, therefore there is little impetus to deal with the problem. Many attempts were made to establish a tax or royalty for a hard-rock mining reclamation fund, similar to what has been done with coal mining. However, the economics of metal mining are fundamentally different from those of coal. Most domestic coal production is used for the generation of electricity. The tax on coal production by SMCRA is passed on to the electric rate payers. Metal mines must compete in an environment where the price of their product is set on a world scale. Imposition of a similar production tax or royalty cannot be passed on to the customer. Realizing that only modest funding would be available to deal with the abandoned hard-rock mines in the United States, Federal and State agencies, and interested non-governmental agencies, began meeting initially on an informal basis and later as a chartered interagency taskforce to find ways to deal with the problem. Two important concepts came out of those meetings. The first was the formation of partnerships among stakeholders in order to most effectively use the resources of each agency, organization, and interested individual to leverage funds, expertise,

and voluntary labor, including the use of matching funds. The second concept was a recommendation that a "Watershed Approach" be applied to the remediation of the Nation's abandoned hard-rock mines. The Watershed Approach would be applied by evaluating the abandoned mines in the watershed, giving priority to reclaiming those that were causing the most significant shares of the pollution, especially those significant polluters that could be easily reclaimed. These concepts sought to achieve the greatest improvement in watershed quality using limited funds. The suggestions were readily accepted, and USGS became the main proponent in fostering the Watershed Approach to mine cleanup by application of a substantial scientific effort that continues to this day (Church, and others, 2007a). It is in this environment that EPA has been cooperatively working with DRMS and ARSG to leverage limited funds to undertake projects such as remediation of the Red and Bonita and Gold King Mines.

Some General Observations Regarding the Current State of Practice

There are more than 100,000 abandoned mines and prospects in the western United States. Beginning in the late 1980s, field programs were initiated to locate these mines, inspect them, and record their associated physical hazards (open shafts, unstable structures, etc.) and potential environmental hazards (presence of acid drainage, unused chemicals, eroding mine waste piles, etc.). At this point, the inventory process is at an advanced stage—most states and Federal land management agencies have detailed inventory reports about abandoned mine sites. These inventories, however, have not been screened about the potential for a blowout. It will take a significant effort to make the additional assessment regarding blowout potential.

From a national perspective, large hard-rock mine tailings dams and waste impoundments are already subject to Federal and State dam safety regulations. Abandoned hard-rock underground mines and flooded pit lakes are not subject to similar requirements; experience indicates that they should be. They represent a form of decaying infrastructure that is poorly maintained and, some of which, can fail with disastrous results. A collapsed flooded mine is in effect a dam, and failure must be prevented by routine monitoring, maintenance, and in some cases remediation. However, there appears to be a general absence of knowledge of the risks associated with these facilities. A comprehensive identification of sites, evaluation of the potential to fail, and estimation of the likely downstream consequences should failure occur, are good first steps in such an endeavor.

In addition, there is a growing inventory of underground mines in this nation that are being fitted with hydraulic bulkheads to minimize seepage. Although the coal mine bulkheads are subject to regulation under the Surface Mining Control and Reclamation Act (SMCRA), no comprehensive program exists to deal with the long-term care and maintenance of the hard-rock mine facilities. Many design

documents and some State permit approvals describe these bulkheads as facilities requiring little to no maintenance. Although they will last for many years, they have a finite life and require monitoring and maintenance. Although bulkhead failures are likely to lead to environmental contamination, a blowout caused by the failure of a mine bulkhead at the Marcopper mine in the Philippines resulted in the death of livestock and evacuation of approximately 1,200 people. The designs and monitoring and maintenance requirements for all mines having hydraulic bulkheads are important documents that should be added to the National Mine Map Repository. The potential consequences of a bulkhead failure should be evaluated. If the likely consequences of failure are potentially severe, then inundation maps, emergency action plans, and provisions for monitoring should be developed or enhanced for those facilities as necessary.

Findings

BOR found that the conditions and actions that led to the Gold King Mine incident are not isolated or unique and are, in fact, surprisingly prevalent. The standards of practice for reopening and remediating flooded inactive and abandoned mines are inconsistent from one agency to another. Various guidelines exist for this type of work, but there is little in actual written requirements that government agencies are required to follow when reopening an abandoned mine.

The uncontrolled release at Gold King Mine was the result of a series of events spanning several decades. Groundwater conditions in the upper reaches of Cement Creek have been significantly altered by the establishment of extensive underground mine workings, the extension of the American Tunnel to the Sunnyside Mine, and the subsequent plugging of the American Tunnel. The final events leading to the blowout and uncontrolled release of water occurred because of a combination of an inadequately designed closure of the mine portal in 2009 and a misinterpretation of the groundwater conditions when reopening the mine portal in 2014 and 2015.

In attempting to reopen the Gold King Mine, EPA, in consultation with DRMS, concluded that the adit was partially full of water based excavations made into the downstream side of backfill placed at the portal. Adit seepage was observed in the downstream excavations to be emerging at an elevation about 6 feet above the adit floor. It was incorrectly concluded that the water level inside the mine was at a similar elevation, a few feet below the top of the adit roof. This error resulted in development of a plan to open the mine in a manner that appeared to guard against blowout but instead led directly to the failure.

The collapsed material in the adit and the backfill added in 2009 were derived from the collapsed rock and soil that contained a significant amount of clay. It was not a typical roof collapse comprised mostly of cohesionless, broken rock. The clay content contributed to the significant attenuation (head loss) of flow in the collapsed debris and backfill as the mine water flowed through it. In addition, deposition of iron-oxyhydroxide sediment inside the mine likely contributed to additional reductions in the seepage flow as the sediment layer grew thicker with the passage of time. Changes in seepage were observed and documented in photographs in both 2014 and 2015, but its implications with respect to attenuation of the flow through the fill were not accounted for.

After the EPA project team concluded that the adit was not full to the top with water, they implemented a plan to open the mine in a manner similar to the one used successfully to reopen the adit at the nearby Red and Bonita Mine in 2011. The plan consisted of excavating the fill to expose the rock crown over the adit

but leave the fill below the adit roof in place. Then a steel pipe ("stinger") would be inserted through the fill and into the mine pool, a pump would be attached, and the water in the mine would be pumped down.

A critical difference between the Gold King plan and that used at the Red and Bonita Mine in 2011 was the use of a drill rig to bore into the mine from above to directly determine the level of the mine pool prior to excavating backfill at the portal. Although this was apparently considered at Gold King, it was not done. Had it been done, the plan to open the mine would have been revised, and the blowout would not have occurred.

The incident at Gold King Mine is somewhat emblematic of the current state of practice in abandoned mine remediation. The current state of practice appears to focus attention on the environmental issues. Abandoned mine guidelines and manuals provide detailed guidance on environmental sampling, waste characterization, and water treatment, with little appreciation for the engineering complexity of some abandoned mine projects that often require, but do not receive, a significant level of expertise. In the case of the Gold King incident, as in many others, there was an absence of many essential things:

1. An understanding that water impounded behind a blocked mine opening can create hydraulic forces similar to those in a dam.

2. Analysis of potential failure modes.

3. Analysis of downstream consequences if failure were to occur.

4. Engineering considerations that analyze the geologic and hydrologic conditions of the general area.

5. Monitoring to ensure that the structure constructed to close the mine portal continues to perform as intended.

6. An understanding of the groundwater system affecting all the mines in the area and the potential for work on one mine affecting conditions at another.

It is important to note that although the USACE peer reviewer agreed that the report properly describes the technical causes of the failure, he had serious reservations with the chronology of events internal to EPA from the day of the telephone call to BOR and up to the day of the mine failure. He pointed out that the actual cause of failure is some combination of issues related to EPA internal communications, administrative authorities, and/or a break in the decision path, and that the report was non-specific regarding the source of information in regard to EPA documents and interviews with EPA employees and the onsite contractor. The USACE believes that the investigation and report should have described what

happened internal within EPA that resulted in the path forward and eventually caused the failure. The report discusses field observations by EPA (and why they continued digging), but does not describe why a change in EPA field coordinators caused the urgency to start digging out the plug rather than wait for BOR technical input as prescribed by the EPA project leader.

The BOR evaluation team believed that it was hired to perform a technical evaluation of the causes of the incident, and was not asked to look into the internal communications of the onsite personnel, or to determine why decisions were made. The evaluation team did not believe it was requested to perform an investigation into a "finding of fault," and that those separate investigative efforts would be performed by others more suitable to that undertaking.

Recommendations

The evaluation team offers the following recommendations:

1. Because of the complexity of reopening a flooded abandoned mine, a potential failure modes analysis should be incorporated into project planning.

2. Before opening an abandoned mine adit, review mine maps, production records, dump size, and local history about the mine to evaluate the potential volume of mine workings. If the volume is large, consider what would happen if there were an accidental release and what could be done to protect against it. A downstream-consequences analysis should be a part of every complex mine remediation.

3. Water conditions within the mine should be directly measured prior to opening a blocked mine. Indirect evidence is insufficient if the potential for a blowout exists.

4. Where significant consequences of failure are possible, independent expertise should be obtained to review project plans and designs prior to implementation.

Glossary of Terms

Acid-Rock Drainage –Water flow that is contaminated by exposure to rock containing sulfide minerals such as pyrite (iron sulfide). The oxidation of sulfide minerals produces sulfuric acid, sulfate, and dissolved heavy metals that contaminate the water they come in contact with.

Acre-foot – A measure of water volume that is defined as a layer of water one foot thick covering one acre of land. One acre-foot is equal to 325,851 gallons of water.

Adit – A horizontal or gently inclined excavation made into the side of a hill or mountain to provide underground access. Adits commonly are driven with an uphill slope (about 1%) to provide drainage such that groundwater seepage will readily flow out of the excavation and discharge to the surface. An adit is only open to the ground surface on one end, the other end may be a dead end or it may connect to a shaft, raise or other type of mine passage that could eventually reach the ground surface.

Attenuate – To reduce the force, volume, or magnitude of something. For example, when a valve placed along a flowing pipe is partially closed it attenuates (reduces) the flow.

Blowout – A sudden, violent, release of gas or liquid due to the reservoir pressure in a drill hole or mine.

Breccia – A rock composed of angular, broken rock fragments held together by mineral cement or a fine-grained matrix.

Caldera – a large depression formed in volcanic rock with an approximately circular shape.

Crown – In mining usage, it is the rock at the top of an adit or stope. It is also called the roof or back.

Dam – Any artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material, for the purpose of storage or control of water. Dams 25 feet or more in height or dams having the ability to impound 50 acre-feet or more of water are subject to Federal regulation (FEMA, 1979)

Dam Failure – Catastrophic failure characterized by the sudden, rapid, and uncontrolled release of impounded water.

Ferricrete – A mass of soil and rock particles cemented by iron-oxyhydroxide formed in surface drainages as a byproduct of the oxidation of acid rock drainage.

ft^3/s – an abbreviation for cubic feet per second, a unit of measure for rate of flow. One cubic foot per second of flow is equal to 448.83 gallons per minute.

gpm – an abbreviation for gallons per minute, a unit of measure for rate of flow.

Graben – An elongate trough or basin bounded on both sides by faults inclined toward the interior of the trough.

Hydraulic Bulkhead – A structural barrier placed in a mine or tunnel for the purpose of impounding water to flood the mine openings and re-establish the pre-mining groundwater levels. The terms adit plug, mine plug, mine seal, and bulkhead seal also have been used to describe this type of impounding structure.

Iron-oxyhydroxide – A general term for a group of oxidized minerals and amorphous compounds that form in nature due to the weathering of iron-containing rocks and minerals and due to the oxidation of iron-rich waters. It can include minerals such as goethite, lepidocrocite, ferrihydrite, schwertmannite, jarosite, and colloids such as limonite (Wolkersdorfer, 2008). In mine workings it commonly precipitates out, forming sediment composed of orange-brown colloidal-sized particles. These iron minerals have a strong affinity for absorbing metals such as cadmium, lead, arsenic, and other elements when they form. The terms “yellow boy” and “ochre” commonly used in reports about abandoned mines refer to the same material.

Latite – A volcanic rock having large crystals of plagioclase and potassium feldspar with little to no quartz and a finely crystalline to glassy groundmass.

Lode – A mineral deposit consisting of a zone of veins, veinlets, disseminations, or breccias in consolidated rock.

Meteoric water – Water derived from precipitation that passes into the earth and flows through pores and fractures in rock.

Mine – A surface or underground excavation made for the purpose of extracting a valuable mineral commodity such as coal or metal ore.

Portal – A structure constructed at the entrance to an adit or tunnel for the purpose of providing support to the surrounding soil and weathered rock in order to allow safe passage into the underground mine opening.

Potential Failure Modes Analysis – An evaluation method that identifies different ways that a system or structure could fail. It is used to identify key elements associated with a potential failure so they can be further studied and evaluated to identify actions that can be taken to reduce the likelihood of failure.

Shaft – A vertical or steeply inclined excavation from the surface extending down into the ground for the purpose of providing underground access. Related terms are winze and raise. A winze is a similar downward extending excavation but it is initiated from within an underground mine working and therefore is not open to the ground surface. A raise is an upward extending excavation initiated from within an underground mine working. A raise may or may not extend to the ground surface.

Stock – A small globular- or columnar-shaped body of intrusive igneous rock that solidified within the crust of the earth.

Stope – An underground excavation from which ore has been removed.

Tuff – A volcanic rock formed of consolidated or cemented volcanic ash.

Tunnel – A horizontal or gently inclined excavation that penetrates a hill or mountain and is open to the surface on both ends such as a highway tunnel or railroad tunnel. The term tunnel is commonly misused in mining to refer to long adits. For example, the American Tunnel is actually an adit because it does not extend to the opposite side of the mountain.

Waste-Rock Dump – A pile of rock and soil placed onto the ground surface immediately outside of a mine entrance as a means of disposal of unwanted material that must be broken and excavated to gain access to the ore in the mine.

Watershed – An area of land that drains to a particular stream or river.

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Appendix A

Uncontrolled Releases of Mine Water in the United States

Uncontrolled Releases of Mine Water in the United States

The United States has experienced many uncontrolled releases of mine water. Most of these releases have not been documented or have received only brief mention in local newspapers. This table presents information about incidents for which documentation was readily obtainable. Although it includes most major release events, it is not a comprehensive listing.

State	Date of Incident	Name and location of Mine	Description of Uncontrolled Mine Water Release Incident
CA	1992	Keystone Mine, Shasta County	Hydraulic bulkheads were installed in the (main) 400-Level, 275-Level, and in the East Adit to reduce acid drainage to West Squaw Creek, approximately 2 miles upstream of its confluence with Lake Shasta. A blowout occurred uphill from the main adit shortly after installation of the bulkhead.
CA	Circa 2010	Blue Ledge Mine, Siskiyou County	An unnamed adit associated with the mine experienced a small blowout into Joe Creek.
CO	August 29, 1895	Americus and Sleepy Hollow Mines, Gilpin County	This event was not a blowout. The abandoned Fisk Mine pool broke through a natural flow pathway along the vein and flooded two nearby active mines with water. Water rose 100 feet in the mine in 3 minutes. Although about half of the crew escaped, 12 men drowned, and another 2 men were suffocated. A large amount of air devoid of oxygen was displaced from old mine workings, and it filled the Sleepy Hollow Mine from the 300-foot level down to the rising flood waters, making attempts at mine rescue difficult. Henry Prisk; his son, William Prisk; and Tom Williams tried to climb out from just below the 500-foot level. They were soon overcome by the bad air; only Henry Prisk made it to the 300-foot level, where he passed out. A few miners who entered the mine in a rescue attempt found Mr. Prisk lying unconscious near the shaft and took him to the surface, where he was revived. Other attempts to enter the mine for additional rescue failed, due to the bad air (*Rocky Mountain News*, August 30, 1895) (Hyvarinen, and others, 1949). The failure led to a State requirement to determine the location of water in abandoned mines and either drain it or avoid it when mining nearby.
CO	January 19, 1943	Argo Tunnel, Clear Creek County	The Argo Tunnel is a 4.16-mile-long drainage adit that was driven from 1893 to 1910. It was developed as an exploration and ore haulage facility that would intercept and drain hundreds of small mines in the Idaho Springs and Central City mining districts. While driving a drainage crosscut near the Kansas vein, a rock wall in the tunnel burst. A natural watercourse impounded a large a body of underground water. The excavation came close to the watercourse, and the hydraulic pressure caused the rock to burst into the mine. A large inflow of water rapidly flooded the mine, killing four miners. A fifth man was driving an ore train towards the mine exit. He jumped up, ran to the exit, and barely escaped when the water caught up to him as he was emerging from the mine. The blowout sent a surge of water into Clear Creek that lasted several hours and impacted water intakes located downstream. Subsequently, this mine has experienced numerous surges. In 1980, a large blowout, likely due to failure of a temporary dam formed by a collapse, released a large flow that caused the closure of six downstream municipal drinking water intakes. Although the water treatment plant has a surge tank, it cannot handle a large blowout, such as the 1980 event. A current proposal exists to install a flow control bulkhead at the mine at an estimated cost of $500,000.

State	Date of Incident	Name and location of Mine	Description of Uncontrolled Mine Water Release Incident
CO	1978	Sunnyside Mine, San Juan County	While a high grade zone of gold ore was being mined in an upwards direction, the mine workings broke through the bedrock surface into a till soil. Seepage into the mine eroded the soil, eventually resulting in the sudden inrush of Lake Emma into the underground mine. The 500 million gallons of water rapidly surged through the mine, exiting out the adit portal in Eureka Gulch. The blowout was witnessed by a watchman, who described it as shooting out into the canyon. It carried rocks, mud, mining equipment, and timber and caused extensive damage to the mine. No one was in the mine at the time of the blowout.
CO	1994	Summitville Mine, Rio Grande County	The Reynolds Adit had been draining acid mine water since 1906. The Chandler Adit is located 2,400 feet away from, and 150 feet higher in elevation than, the Reynolds Adit. The adits are hydraulically connected by underground mine workings. Concrete plugs were installed from November 1993 to February 1994, using a design based on characterization of the rock in the Reynolds Adit. The plugs resulted in a large decrease of acid and copper loading in the Wightman Fork Creek. The Chandler Adit plug failed in May 1994, leaking its impounded mine pool to the creek. The rock in the Chandler Adit was substantially weaker than in the Reynolds Adit. The rock surrounding the concrete plug failed, resulting in the release of the impounded mine water. In November 1994, a redesigned plug was installed in the Chandler Adit.
CO	Circa 2003	Burlington Mine, Jamestown, Boulder County	The mine operated from 1942 until 1972, producing more than 700,000 tons of fluorite ore. It was developed with 12 levels and had numerous open stopes. The mine was accessed by a shaft and adits. The upper 500 feet of stopes had been partially backfilled with waste rock during mining. In the 1970s, several subsidence events resulted in the formation of a 300-foot-deep surface pit. This large subsidence hole was filled with waste rock and common fill. By 2000, the area had experienced additional subsidence, resulting in a 30-foot-deep pit. The mine was undergoing a reclamation project when a flood occurred, temporarily filling the pit and causing the Warren Adit to blow out, sending waste rock for several miles downstream along James Creek (Cowart and Levin, 2004).
CO	August 5, 2015	Gold King Mine, Silverton, San Juan County	A blowout occurred during an attempt to open and stabilize the old adit on Level 7 of the mine, releasing 3 million gallons of acidic mine water. Afterwards, a sustained base flow out of the mine of approximately 600 gallons per minute (gpm) was observed.
KY	1993-1995	Various locations in eastern Kentucky	A total of 15 coal mine blowouts were recorded in the State during this 2-year period.
KY	October 11, 2000	Martin County Coal Corporation, Inez, Kentucky	A 72-acre coal waste impoundment broke through a coal outcrop pillar and flowed into an underlying underground coal mine. Approximately 250 million gallons of water, mixed with 31 million gallons of coal waste, flowed out two of the mine portals located 2 miles apart, impacting creeks and rivers in two watersheds. Environmental damage occurred, which disrupted drinking water supplies in Kentucky and West Virginia. This incident was the largest industrial spill in the United States until the Kingston, Tennessee, fly ash impoundment failure in 2008. The National Research Council appointed a Committee on Coal Waste Impoundments, which issued a final report with recommendations in January 2002 (Committee on Coal Waste Impoundments, 2002).
KY	April 27, 2005	Helan Ann Mining Company, Cranks, Harlan County	A blowout at noon on Sunday released a 30-foot-wide stream of water, turning Cranks Creek orange and killing fish.

State	Date of Incident	Name and location of Mine	Description of Uncontrolled Mine Water Release Incident
KY	April 17, 2005	Helen Ann Mining Company, Cranks, Harlan County	A blowout at noon on Sunday released a 30-foot-wide stream of water, turning Cranks Creek orange and killing fish.
KY	April 18, 2005	James Fork Mine, Knott County	A blowout occurred from a flooded underground coal mine, which operated during the late 1980s into the early 1990s. The uncontrolled release covered the Hal Rogers Parkway with mud and rocks before entering Rock Fork Creek. The mine covers an area of 800 acres and has been estimated to impound up to 600 million gallons of water if completely flooded. Flow continued at 300 to 400 gpm per week following the blowout.
KY	April 25, 2008	Coal Mine Near Kimper, Pike County	A blowout occurred in an abandoned coal mine that closed in 1995, covering parts of Highway 194 with rocks and debris. Five-hundred people were evacuated.
KY	March, 2009	Bledsoe Coal Corporation Mine, Leslie County	A coal mine that had not been operated since the 1970s blew out, releasing a 10,000-gpm flow of water.
KY	February 23, 2014	Bill's Hall Branch Mine, near McDowell, Floyd County	A mine blowout caused minor property damage.
KY	March 6, 2015	Coal Mine Near Lynch, Harlan County	A mine blowout flooded the streets of Lynch, Kentucky, with mud and rock, requiring several days to clean up and reopen the roads.
MI	Sept. 28, 1893	Mansfield Mine, Crystal Falls, Iron County	This event was not a blowout. While following a rich vein of ore under the bed of a river, the river broke through. The inrush of water filled the mine in less than 5 minutes and drowned 28 miners (Hyvarinen, and others, 1949).
MI	July 14, 1914	Balkan Mine, Palatka, Iron County	This event was not a blowout. About 3 hours after two 10-inch drill holes were blasted, while mining was taking place near the surface, an inrush of sand and water into the raise occurred. Five men escaped and seven men drowned (Hyvarinen, and others, 1949).
MT	November 24, 2008	Golden Anchor Mine, Powell County	The adit blowout resulted in Tramway Creek, located 6 miles south of Elliston and the Little Blackfoot River, running yellow-orange for several days, with high turbidity and elevated levels of arsenic and lead. It was assumed that a collapse had taken place in the mine workings, which temporarily impounded water draining from the adit and resulted in its later blowout.

State	Date of Incident	Name and location of Mine	Description of Uncontrolled Mine Water Release Incident
NJ	October 19, 1911	New Langdon Shaft, Wharton Steel Company, Hibernia, Morris County	This event was not a blowout. The sudden flooding of the mine shaft resulted in the drowning of 12 miners. A drift was being excavated toward old workings that were known to be full of water, while the shaft was being sunk deeper. The drift was 172 feet from the workings, when water broke through after a blast. The water came out of an 18-inch hole, forming a natural watercourse in the rock. The men in the drift were barely able to escape. Although it only had 30 feet of head, five men in the shaft below were unable to climb up against the flow. Seven other men were trapped in mine workings on lower levels of the mine. Lessons learned included the need for accurate mine maps, carrying test holes ahead of the drift while trying to tap old flooded workings, and not allowing people to work below an area that might be flooded. After the flood, the mine was pumped out and deeper in the mine, another drift was driven with test holes that allowed location of the flooded mine workings. The water was safely removed through boreholes (Hyvarinen, and others, 1949). It was a repeat of the 1895 Colorado disaster, and it led to a national requirement to probe ahead by drilling when mining near old flooded mine workings.
PA	1969	Lancashire No. 15 Coal Mine, Cambria County	The mine pool covered an area of 7,100 acres with 1.42 billion gallons of water. The mine closed in 1968, and the mining company ceased pumping operations. In 1969, the rising mine pool blew out, impacting the West Branch of the Susquehanna River. The company was ordered to resume pumping and construct a water treatment facility. The water treatment continued until 1999, when the company filed for bankruptcy. The State has taken over the site. A flow of 4,000 to 6,000 gpm is treated to maintain the mine pool at a constant level and prevent further blowouts.
PA	March 1, 1977	Porter Tunnel, Schuykill County	Water accumulated in mine workings that had been abandoned in the 1940s and suddenly broke into the floor of an advancing gangway (decline), causing an air blast and rapidly inundating a portion of the active mine. Of the 19 miners underground, 9 escaped, 9 drowned, and 1 was eventually rescued. The investigation concluded that the mine maps of the old workings were inaccurate, and the abandoned workings were closer than indicated. Furthermore, the company had required drilling test holes to probe ahead for the flooded workings, including drilling 26-foot-long test holes in the low side rib (towards the abandoned workings). The miners had difficulty drilling the 26-foot-long holes and mine management discontinued the requirement prior to the incident.
PA	July 24, 2002	Quecreek Coal Mine, Somerset County	This event was not a blowout. Nine men were trapped underground in an air pocket, when they drilled into the adjacent abandoned Saxman Mine, which released more than 50 million gallons of water and flooded their work area. The men were rescued by pumping at rates up to 20,000 gpm to lower water levels in the mine, by drilling rescue shafts, and by installing an air lock in the shaft through which the men were extracted. Mine maps showed the abandoned mine to be 300 feet away, but the maps in this mining area were known to be inaccurate. The State revised their regulations to require investigation of flooded mines by mapping, drilling, or other means when mining takes place within 500 feet of an abandoned bituminous coal mine, or within 300 feet of an abandoned anthracite coal mine. The previous requirement was to investigate when within 200 feet of an abandoned mine. Also, the State electronically scanned its 3,900 historic mine maps to make them more radially available.

State	Date of Incident	Name and location of Mine	Description of Uncontrolled Mine Water Release Incident
PA	January 25, 2005	Nickel Plate Coal Mine, McDonald, Washington County	At 2:00 p.m., a blowout occurred, resulting in a flow of approximately 8,000 to 10,000 gpm into the town streets. The mine was extensive, having underground workings below a 1,100-acre area. The problem was remedied by drilling monitoring wells, pumping the mine pool, and installing a permanent drain to take the water to Robinson Run, a tributary of Chartiers Creek. A total of $402,000 was spent from February 28, 2005, until June 15, 2005, to complete the work.
PA	2007	Shawmut No. 33 Coal Mine	A blowout occurred during an attempt to open the mine to construct a seal. Since discharge was flowing from a down dip section of the mine, and this opening was near the most up dip limits of the mine, it was assumed that no mine pool head existed behind the opening. Excavation to find the rock tunnel resulted in a blowout of several million gallons of mine water over a 6-hour period. A total of $543,000 was spent in the Spring of 2007 to complete the mine seal with a drain and weir for measuring flow.
PA	March 2012	Coal Mine Near Hooversville, Somerset County	An abandoned coal mine blowout flooded roads and a bridge.
VA	May 13, 1995	Dominion Coal Company Mine at Big Stone Gap, Wise County	A 25-year-old woman was killed when water from a coal mine blowout flowed down a hollow and into her house around 4:00 a.m. Four other people were able to escape from the home. The State determined that a shale roof collapsed into the coal mine, causing a surge of water to flow out of the mine.
VA	Oct. 1996	Arch Mineral Corporation, Lee County	A waste impoundment broke into old mine workings and blew out.
VA	Nov. 26, 1996	Buchanan No. 1 Mine, Oakwood, Buchanan County	A waste impoundment broke into old mine workings and poured out of the mine at rates of up to 1,000 gpm. On February 11, 1997, the Mine Safety and Health Administration ordered a nationwide examination of the potential for releases from impoundments into underground mines.
WV	2009	Coal Mine at East Bank, Kanawha County	A blowout at 5:35 a.m. created a 12-foot-wide hole in the side of the hill. The East Bank Middle School was evacuated and closed for the day.
WV	2012	Coal Mine, Greenbrier County	Muddy Creek, West Virginia, coal mine blowout.

Appendix B

Hydraulic Mine Bulkheads in the United States

Hydraulic Mine Bulkheads in the United States

Water impounding bulkheads (plugs) have been installed in many mines in the United States. By 1910, the construction of concrete bulkheads was a common practice in the United States as a means to prevent inflow of water into underground mines to protect mine workers. About 60 years later, the same technology of hydraulic bulkheads began to be used to prevent water from flowing out of underground mines. This table was compiled from readily available information about bulkheads installed in the past 25 years to contain water inside of underground mines; it is not a comprehensive listing.

State	Date Installed	Name and Location of Mine	Description of Bulkhead
CA	Late 1950s	Leviathan Mine, Alpine County	The bulkhead was installed by the mining company. This site is considered a Superfund site and has undergone numerous reclamation and water treatment projects. An active water treatment plant is currently being designed for the site.
CA	November 1980	Weil Tunnel, Shasta County	After installation in November 1980, an additional 18-inch-thick layer of concrete was added in December 1981, followed by another 20-inch-thick layer in 1987, to strengthen the seal. The former 60 gallons per minute (gpm) of flow was eliminated, and monitoring shows a pressure of 92 to 107 pounds per square inch (psi). Maximum pressure is controlled by the 170-Level portal, which lies 230 feet above the bulkhead (Regional Water Quality Control Board, Central Valley Region, 2004).
CA	1987	Walker Mine, Plumas County	A concrete bulkhead was installed 2,700 feet inside the 700-Level mine adit.
CA	1987	Early Bird Adit, Shasta County	A hydraulic bulkhead was installed in this adit to reduce acid drainage into West Squaw Creek, about 2.5 miles upstream of the confluence with Lake Shasta. Due to leakage, boreholes were drilled, and the rock around the bulkhead was pressure grouted in the Summer of 1989. Metals loading of the stream has been eliminated (Regional Water Quality Control Board, Central Valley Region, 2004).
CA	July 1989	Shasta King Mine, Shasta County	A bulkhead was installed in July 1989 in the Lower Shasta King Adit. There was significant leakage through fractures. Repairs in 1991 and 1994 were not successful. In 2003, a second bulkhead was installed in front of the original structure, and a grout curtain was injected.
CA	1985	Balaklala Mine, Shasta County	Installation of hydraulic bulkheads in the Balaklala Adit and the Upper Windy Camp Adit reduced seepage discharge to West Squaw Creek, about 2 miles upstream of the confluence with Lake Shasta. In 1988, the original seal leaked and failed along its toe; but it was replaced in October 1988. In 1989, boreholes were drilled, and the rock surrounding the new bulkhead was pressure grouted, which reduced seepage by 99% (Regional Water Quality Control Board, Central Valley Region, 2004).

State	Date Installed	Name and Location of Mine	Description of Bulkhead
CA	1981-1997	Mammoth Mine, Shasta County	Multiple hydraulic bulkheads were installed. The 1981 bulkhead in the Main Mammoth Portal caused acid seepage to emerge from the Friday-Louden Adit, so it was plugged in 1983; however, this caused flow from the 300-Level Adit, the Gossen No. 2 Adit, the East 470 Adit, and the North 470 Adit. All of the other openings were bulkheaded by 1983. While acid drainage from the mine openings has been minimized or eliminated, acid seepage continues through fractures in the rock. The Friday-Louden Portal showed pressure readings of up to 240 psi; but in 1995, the pressure dropped and a significant acid spring was discovered on a steep slope west of, and several hundred feet below, the Main Mammoth Portal. The pressure is now about 180 psi (Regional Water Quality Control Board, Central Valley Region, 2004).
CA	1992	Keystone Mine, Shasta County	Hydraulic bulkheads were installed in the (main) 400-Level, 275-Level, and in the East Adit to reduce the 80 gpm of acid drainage to West Squaw Creek, approximately 2 miles upstream of its confluence with Lake Shasta. A blowout occurred uphill from the main adit shortly after installation of the bulkhead. In 1999, a remote bulkhead was placed by injecting limestone to create two cofferdams and injecting concrete to form a seal between the limestone. This seal only reduced flow for a short period of time. In 2001, an additional 24 boreholes were drilled near the remotely placed seal, the mine was dewatered, and more concrete was injected. This reduced the acid flow from 80 gpm to 45 gpm (20 gpm from the blowout and 25 gpm from the 400-Level bulkhead). A passive wetlands treatment system was installed in 2004 downstream of the acid flow (Regional Water Quality Control Board, Central Valley Region, 2004).
CA		Stowell Mine, Shasta County	A bulkhead was installed to reduce acid drainage to Spring Creek, about 5 miles upstream of Keswick Reservoir.
CA	1991	Mason Mine, Shasta County	A bulkhead was installed to reduce acid flow to the North Fork of Little Backbone Creek, about 1.5 miles upstream of its confluence with Lake Shasta.
CA	2001	Golinsky Mine, Shasta County	Two bulkhead seals were installed to control acid drainage. A short time after the installation, drainage from the number three adit deteriorated from neutral-pH conditions to pH 3 drainage conditions. Investigations showed that the mine pool was varying from 70 to 33 feet in head on an annual basis, and dissolved oxygen content of the mine pool did not decline as expected. A downstream passive bioreactor water treatment system was installed to mitigate the flow from the number 3 adit (Gusek, and others, 2011).
CA	2004	Rising Star Mine, Shasta County	Two portals were sealed to reduce acid drainage seepage flows.

State	Date Installed	Name and Location of Mine	Description of Bulkhead
CO	1973	Leadville Mine Drainage Tunnel, Lake County	The Leadville Mine Drainage Tunnel is a Bureau of Reclamation managed facility that was installed by the U.S. Bureau of Mines. In response to the continued formation of sinkholes in alluvium above the tunnel, a porous plug of gravel fill was remotely placed into the tunnel by drilling percussion holes every 10 feet from the surface and injecting gravel into the tunnel voids. The bulkhead was designed to be pervious so that drainage outflow could be sustained. In 1976, additional sinkholes formed. A decision was made to reopen the tunnel. At 466 feet in, a new steel-and-timber bulkhead with openings to pass flow was installed, and additional gravel was placed upstream of the bulkhead. In 1990-1992, an additional 5 feet of gravel and cobble fill was placed, and another porous timber lattice bulkhead was installed downstream to hold the cobbles in place. The use of finer gravel provided a better filter for the alluvium, and this has minimized the formation of sinkholes. In November 2007, the U.S. Environmental Protection Agency (EPA) released a letter expressing concern that an uncontrolled release of water from the tunnel could occur, due to continued caving in the tunnel, and result in decreased drainage outflow and rising water levels in the upstream portions of the tunnel. The Bureau of Reclamation undertook an engineering analysis that showed the gravel-fill bulkhead would resist large hydraulic pressures and that a blowout was highly unlikely. Additional monitoring wells were drilled, and pressure monitoring instruments were installed as a precaution (Bureau of Reclamation, 2008).
CO	1986	Eagle Mine, Eagle County	Eight concrete bulkheads were installed in the Eagle, Tip Top, and Ben Butler Mines to inundate the mine workings and reduce discharges of acid water to the Eagle River. Bulkhead number 5 includes piping that enables the mine pool to be drawn down and conveyed to water treatment.
CO	2012	Keystone Mine, Mt. Emmons, Gunnison County	In 2012, adit rehabilitation work was performed to access a bulkhead located 4,800 feet in from the portal. A clean water bypass was installed to allow mine drainage to flow out of the mine without contacting acid generating portions of the mine workings.
CO	1993	American Tunnel, Sunnyside Mine, San Juan County	Three 25-foot-long concrete bulkheads were installed by Sunnyside Gold, Inc., to minimize adit drainage and restore premining groundwater conditions. The first bulkhead was installed in 1993, followed by installation of a second bulkhead in 2002. Around 1997, 652 tons of hydrated lime were injected into the mine pool to neutralize the water and help reduce pyrite oxidation and acid generation.
CO	Jan. 25, 1994	Reynolds Adit, Summitville Mine, Rio Grande County	Two hydraulic bulkheads were placed in series in the Reynolds adit. The bulkheads include pipe penetrations with valves for draining the impounded mine pool and sensors for pressure monitoring. Site groundwater elevations are also monitored at various locations via a network of vertical drill holes into bedrock and one well drilled into the mine pool. A 2-month-long drawdown test showed that the head was lowered by 250 feet at a discharge rate of 500 gpm. It was estimated that the bulkheads were impounding 14 acre-feet of water (Cox, and others, 2002).
CO	February 1994	Chandler Adit, Summitville Mine, Rio Grande County	One hydraulic bulkhead was installed. It blew out in May 1994 because its design was based on characterization of the rock in the Reynolds Adit, but the Chandler Adit rock was more altered and weaker (Einarson and Abel, 1990). Seepage eroded the rock surrounding the plug and led to uncontrolled draining of the mine pool. The bulkhead was redesigned and reconstructed in November 1994 (Gobla, 1999).

State	Date Installed	Name and Location of Mine	Description of Bulkhead
CO	1995	Pinnacle Adit, Saguache County	A 40-foot-long concrete plug was placed by injection through 15 drill holes from the surface to inundate the Pinnacle uranium mine. The plug retains heads of up to 90 feet of water and greatly reduces the adit water discharges (Cremeens, and others, 1998).
CO	1997	Gold Prince Mine, San Juan County	Bulkheads were placed by Sunnyside Gold, Inc., to stop mine drainage.
CO	1997	Ransom Mine, San Juan County	A bulkhead was placed by Sunnyside Gold, Inc.
CO	2003	Mogul Mine, San Juan County	A bulkhead was installed to minimize acid drainage to Cement Creek.
CO	May 2002	Ten Mile Tunnel, Climax Mine, Summit County	Emergency repair began in September 2001 to reopen a collapsed portion of tunnel that extended beneath the Climax Tailings Dam. After opening the area, a 12-foot-thick concrete plug was blasted out and replaced with a new concrete bulkhead, incorporating drain pipes, valves, and a high-pressure door to allow equipment to pass through for future tunnel maintenance.
CO	2003	Roy Pray Mine, Hinsdale County	A bulkhead was placed to minimize flow from the adit. Initial monitoring showed a decrease in flow and metals loading, followed by an increase in both. Acid water flows have increased to similar levels prior to reclamation, while metals loading is reduced but showing an increasing trend (Bembenek, article posted online).
CO	2009	Dinero Tunnel, Lake County	The Bureau of Land Management funded the Colorado Division of Minerals and Geology to reopen, evaluate, and plug the adit that was impacting Lake Fork Creek. Prior to plugging, acid water outflow varied from 32 gpm to 220 gpm, with the high flows occurring during the late spring and early summer. Also, there was evidence that the tunnel had experienced small blowouts in the past. From 2003 to 2005, the site was investigated. A collapse zone was found about 400 feet in from the portal. As a precaution against a potential blowout, prior to excavation, a hole was drilled from the surface upstream of the collapse to investigate if there was a mine pool. Later, a second larger collapse zone impounding the mine pool was encountered 1,980 feet in from the portal. The project team decided to install a steel-reinforced, concrete bulkhead 1,250 feet in from the portal, where massive unfractured granite was observed. After bulkhead installation, the water table rose 377 feet. Flows from adjacent natural springs and a nearby small mine increased, and water quality degraded due to the elevated water table; however, the effects were largely contained by the Dinero wetland area. With the greatly reduced flow out of the Dinero Tunnel, the downstream water quality improved (Walton-Day, and others, 2013).
CO	2008	Schwartzwalder Mine, Jefferson County	Two hydraulic bulkheads were constructed near large open stopes, which required investigation of the mine voids and a grouting program to ensure the integrity of the mine seals.
CO	2014	Pennsylvania Mine, Summit County	The first of two planned bulkheads was installed in 2014.

State	Date Installed	Name and Location of Mine	Description of Bulkhead
ID	2003	Triumph Tunnel, Blaine County	Asarco Mining Company provided $300,000 to construct a hydraulic bulkhead at the Triumph Mine. Monitoring showed that water pressure increased for 2 years, reaching 50 psi in July 2005. The pressure remained steady for half a year, then began a steady increase to 100 psi in September 2006. In the next 2 years, it increased to 110 psi and has stayed steady, with a mine pool depth of 250 feet. The adit flow of 90 to 190 gpm of acid water decreased to about 4 gpm of seepage discharges after plugging (Idaho Department of Environmental Quality, 2009).
MT	1996	Mike Horse Mine, Powell County	A bulkhead was installed on the main adit. The mine pool was found to vary in elevation, with each spring snowmelt releasing metals to the creek. In October 1996, 18,000 lb of organic carbon and nutrients were added to the mine pool, and another 40,000 pounds were added in July 1997. This caused the ferrous to total iron ratio to change from 0.5 to 1.0, and heavy metals precipitated out, indicating that reducing conditions had been established. With each spring flush, oxidizing conditions returned, requiring additional dosing of the mine pool (Harrington, 2002).
MT	2005	Glengary Adit, Park County	After reconditioning 3,000 feet of mine workings, four major areas of water inflow were identified. The mine closure included grouting water transmitting fractures, grouting fractured rock around the collar of a raise, selective backfilling of portions of the underground workings, installation of five water-impounding plugs, and installation of an earthen backfill plug at the portal. The raise closure included a 14-foot-long concrete plug, on top of which was a 4-foot-long bentonite clay plug; above and below the plugs, a total of 637 cubic yards of 1,800-psi soil-cement backfill was placed. The fill and plugs filled the upper 230 feet of the 490-foot-tall raise. Four cement-sand plugs were installed in the adit, and a 386-foot-deep monitor well was drilled from the surface to the mine pool just upstream of the upstream-most plug. Within 60 days of plug installation, the monitor well filled and had artesian flow of 0.5 gpm. The work took 3 years and cost $3.28 million to construct. The acid drainage contributed about 30% of the loading to Fisher Creek and was reduced from an average of 59 gpm before closure to about 2 gpm after closure. No future operational, maintenance, or treatment costs are anticipated (Marks, and others, 2008).
SD	2005	Homestake Mine, Lawrence County	Three tunnels were sealed, and one tunnel received a bulkhead that was sealed using ultrafine grout.

Appendix C

Soil Sampling Summary

Soil Sampling Summary

A Bureau of Reclamation (BOR) engineer met representatives of the U.S. Environmental Protection Agency, Region 8 (EPA); Environmental Restoration, LLC (ER); and Westin Solutions, Inc., Superfund Technical Assessment and Response Team (Weston) at the Gold King Mine site to collect soil samples on September 15, 2015. The objective was to collect representative samples of soils that could have been impounding water in the Gold King Mine Level 7 New Adit prior to the uncontrolled release that occurred on August 5, 2015. The BOR engineer met the EPA, ER, and Westin representatives at the Gladstone staging area and was escorted to the Gold King Mine Level 7 New Adit portal. After consulting with personnel at the site on August 4 and 5, during excavation activities prior to the release, two stockpiles were identified as having soil excavated from in front of the Gold King Mine Level 7 New Adit portal. Two composite bulk samples were collected from each stockpile. Four 5-gallon buckets of soil were collected for each sample.

Sample No. 1 was collected from an approximately 2-foot-high berm along the downslope edge of the waste rock pile (Figure C-1). According to onsite personnel, this safety berm was constructed from a stockpile of soil that was excavated from in front of the portal.

Sample No. 2 was collected from a stockpile located on the west (left side of the portal when looking into the adit), as shown in Figure C-2.

Samples retrieved during the site visit were returned to the laboratory to be blended and split into representative specimens for testing. The soils were also inspected by a geotechnical engineer. Both samples were classified in general accordance with the Unified Soil Classification System (USCS). An additional, applicable, laboratory testing program was formulated to estimate the soil hydraulic conductivity parameters.

The laboratory tests were performed to provide further understanding of the soils' behavior under the loading conditions prior to the uncontrolled release of the water impounded in the mine adit. Laboratory tests were performed in general accordance with applicable accepted standards.

The soil samples were tested for the following engineering behavioral parameters:

- Water content
- Hydraulic conductivity
- Plasticity index
- Particle size

Figure C-1.—Photograph showing the safety berm made of soil that was excavated from in front of the Gold King Mine Level 7 New Adit portal. Sample No. 1 consisted of soil sampled from various locations along the safety berm.

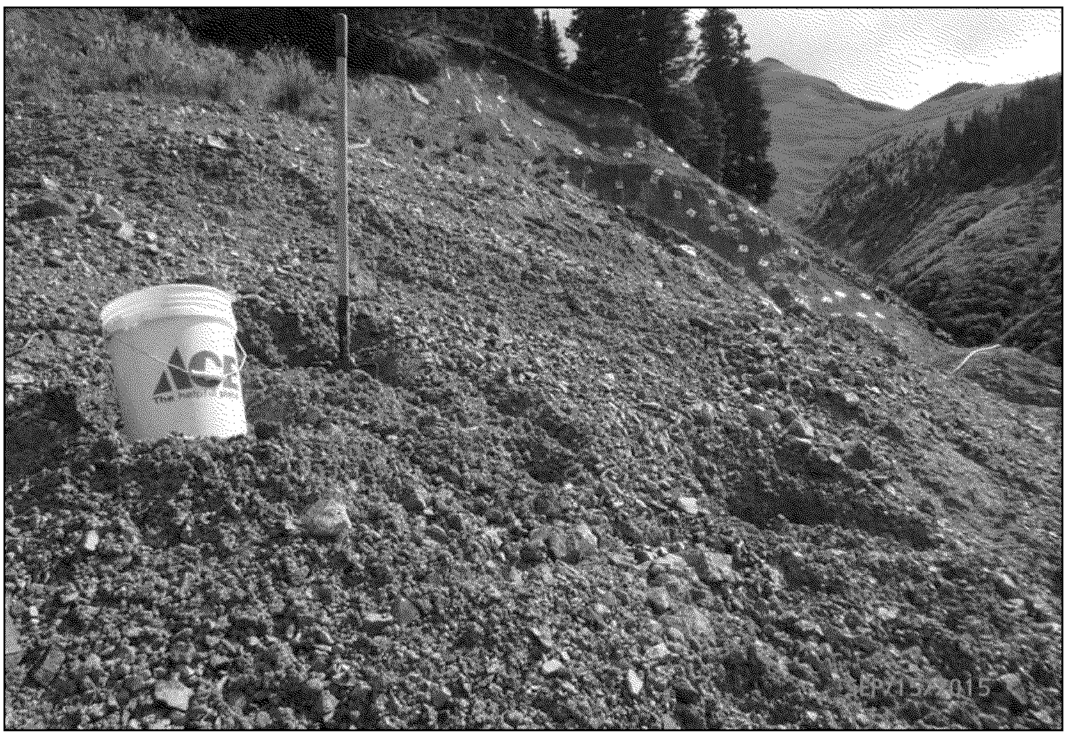


Figure C-2.—Photograph of stockpile where Sample No. 2 was collected. The rock anchors supporting the Gold King Mine Level 7 portal can be seen in the background.

After the samples were blended and split, one 5-gallon bucket for each sample was delivered to the Golder Associates (Golder) soils laboratory in Lakewood, Colorado. Golder laboratory personnel conducted Atterberg-limit tests, particle-size analysis, and hydraulic conductivity testing. Detailed laboratory test results are summarized in Table C-1. The laboratory test results are presented at the end of this appendix.

Table C-1.—Summary of the Laboratory Testing Results

	Sample No. 1	**Sample No. 2**
USCS classification	GC	GC
Liquid limit	37	36
Plastic limit	23	23
Percent finer than 0.075 millimeter (mm) (No. 200 sieve)	17	12
Percent finer than 4.75 mm (No. 4 sieve)	46	38
Percent finer than 19 mm (3/4-inch sieve)	77	77
Hydraulic conductivity (centimeters per second)	3.6×10^{-3}	3.4×10^{-4}

Atterberg Limits and Gradations

Golder Associates

September 28, 2015 Our Ref.: 1405578

United States Bureau of Reclamation
P.O. Box 25007
Denver, CO 80225

Attention: Chris Gemperline

RE: LABORATORY TEST RESULTS FOR USBR PROJECT – GOLD KING MINE

Dear Mr. Chatfield:

Golder Associates Inc. (Golder) has prepared this report to present the results of geotechnical laboratory testing conducted at Golder's Soils Laboratory in Lakewood, Colorado. This report presents a summary table and the results of index testing (Atterberg Limits and grain size distribution) on samples: "#1" and "#2". All pending laboratory test results will be sent when testing has been completed.

Thank you for the opportunity to provide these laboratory testing services and we look forward to assisting you on any future projects.

Should you have any questions or comments, please do not hesitate to call.

Sincerely,

GOLDER ASSOCIATES INC.

Matt Barrett

Matt Barrett
Lab Manager/Senior Consultant

cc: File

mjb/MJB

Attachments (3 pages)

Golder Associates Inc.
9197 West 6th Ave, Building C Suite 100
Lakewood, CO 80215 USA
Tel: (303) 980-0540 Fax: (303) 985-2080 www.golder.com

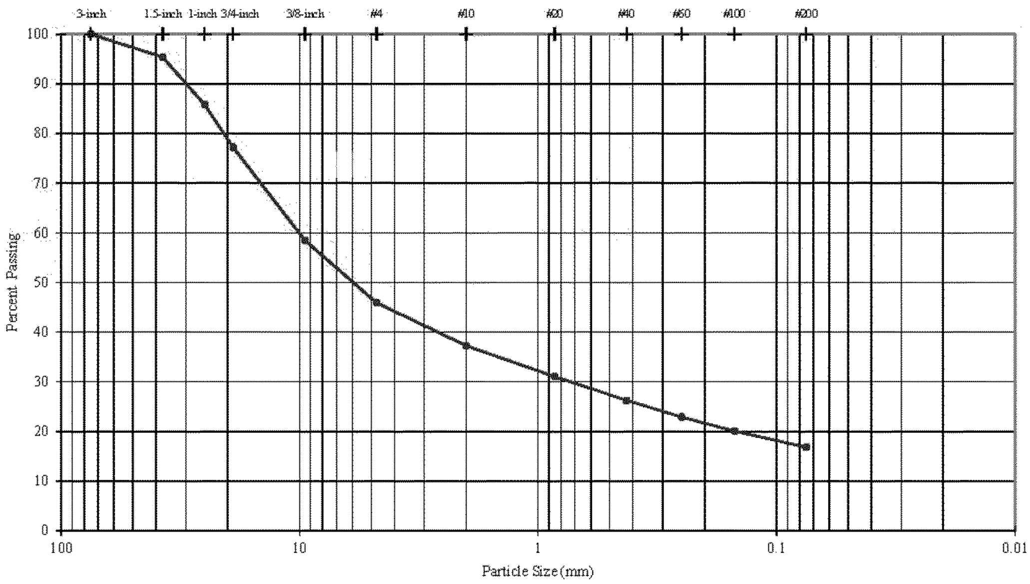
Golder Associates

September-15 | 1405578

PARTICLE SIZE DISTRIBUTION & ATTERBERG LIMITS

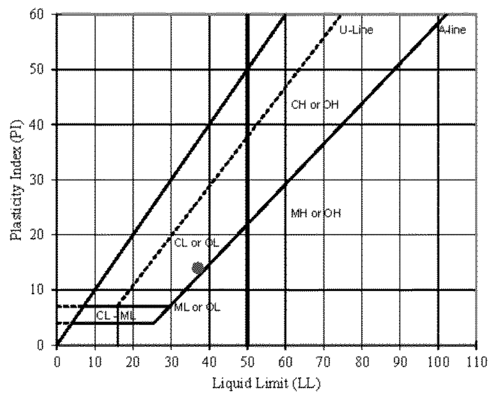
ASTM D421, D422, D4318

PROJECT NAME: **USBR/Lab Testing - 2014/CO**
SAMPLE ID: **#1** DEPTH (ft): --
TYPE: **Pail**



Sieve Analysis (Initial Separation on No. 4 Sieve) Sieve	Particle Size (mm)	% Passing
3-inch	75.0	**100.0**
1.5-inch	37.5	**95.4**
1-inch	25.0	**85.8**
3/4-inch	19.0	**77.2**
3/8-inch	9.5	**58.5**
#4	4.8	**45.9**
#10	2.00	**37.3**
#20	0.85	**31.0**
#40	0.43	**26.3**
#60	0.25	**22.9**
#100	0.15	**20.1**
#200	0.075	**16.8**

Description	Percentage
Coarse Gravel	**22.75**
Fine Gravel	**31.36**
Coarse Sand	**8.63**
Medium Sand	**10.98**
Fine Sand	**9.46**
Silt or Clay Fines	**16.82**



Visual Description:

Clayey gravel with sand, yellowish brown, moist

LL	PL	PI
37	**23**	**14**

As-Received Moisture Content (%): --

USCS Group Symbol: GC

Notes: 0 g of particles up to 75.0 mm maximum size were removed from particle size analysis sample prior to testing
Particle size analysis sample was not mechanically dispersed; hydrometer test was not performed
Sample prepared for Atterberg Limits testing by the dry method
Material retained on No. 40 sieve removed from Atterberg Limits sample by sieving
Plastic Limit test performed by hand rolling. Method A Liquid Limit test performed using mechanical device

TECH	MGC
DATE	9/23/2015
REVIEW	PRH

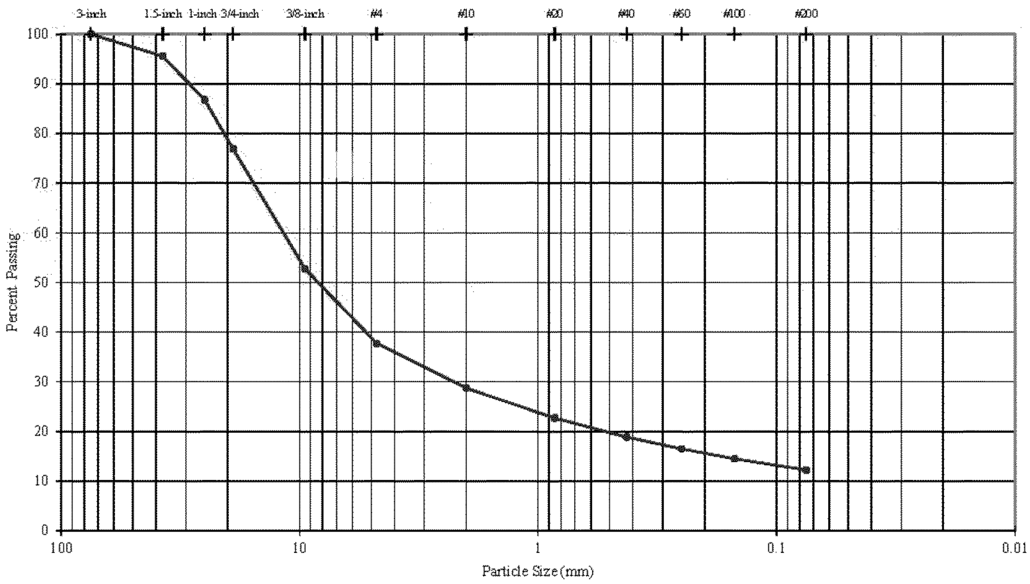
Golder Associates

September-15 1405578

PARTICLE SIZE DISTRIBUTION & ATTERBERG LIMITS

ASTM D421, D422, D4318

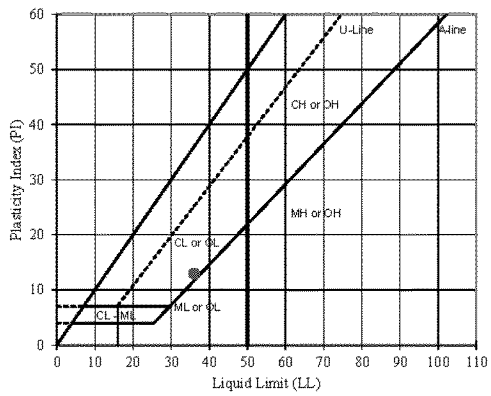
PROJECT NAME: **USBR/Lab Testing - 2014/CO**
SAMPLE ID: **#2** DEPTH (ft): --
TYPE: **Pail**



Sieve Analysis (Initial Separation on No. 4 Sieve)

Sieve	Particle Size (mm)	% Passing
3-inch	75.0	**100.0**
1.5-inch	37.5	**95.6**
1-inch	25.0	**86.8**
3/4-inch	19.0	**76.9**
3/8-inch	9.5	**52.8**
#4	4.8	**37.7**
#10	2.00	**28.7**
#20	0.85	**22.7**
#40	0.43	**18.9**
#60	0.25	**16.5**
#100	0.15	**14.5**
#200	0.075	**12.2**

Description	Percentage
Coarse Gravel	**23.12**
Fine Gravel	**39.15**
Coarse Sand	**9.02**
Medium Sand	**9.84**
Fine Sand	**6.63**
Silt or Clay Fines	**12.24**



Visual Description:

Clayey gravel with sand, yellowish brown, moist

LL	PL	PI
36	**23**	**13**

As-Received Moisture Content (%): --

USCS Group Symbol: GC

Notes: 0 g of particles up to 75.0 mm maximum size were removed from particle size analysis sample prior to testing
Particle size analysis sample was not mechanically dispersed; hydrometer test was not performed
Sample prepared for Atterberg Limits testing by the dry method
Material retained on No. 40 sieve removed from Atterberg Limits sample by sieving
Plastic Limit test performed by hand rolling. Method A Liquid Limit test performed using mechanical device

TECH	MGC
DATE	9/22/2015
REVIEW	PRH

Hydraulic Conductivity

Golder Associates

October 2, 2015 Our Ref.: 1405578

United States Bureau of Reclamation
P.O. Box 25007
Denver, CO 80225

Attention: Chris Gemperline

RE: LABORATORY TEST RESULTS FOR USBR PROJECT – GOLD KING MINE

Dear Mr. Chatfield:

Golder Associates Inc. (Golder) has prepared this report to present the results of geotechnical laboratory testing conducted at Golder's Soils Laboratory in Lakewood, Colorado. This report presents the results of Hydraulic Conductivity testing on Sample "#1". All assigned laboratory testing has been completed.

Thank you for the opportunity to provide these laboratory testing services and we look forward to assisting you on any future projects.

Should you have any questions or comments, please do not hesitate to call.

Sincerely,

GOLDER ASSOCIATES INC.

Matt Barrett

Matt Barrett
Lab Manager/Senior Consultant

cc: File

mjb/MJB

Attachments (4 pages)

Golder Associates Inc.
9197 West 6th Ave, Building C Suite 100
Lakewood, CO 80215 USA
Tel: (303) 980-0540 Fax: (303) 985-2080 www.golder.com

RIGID-WALL COMPRESSION
CONSTANT-HEAD PERMEABILITY
10-INCH DIAMETER CELL

Project Title:	USBR/Lab Testing - 2014/CO			**Boring:**	--
Project Number:	1405578			**Sample:**	#1
Dates Tested:	9/30/2015	**To:**	10/1/2015	**Depth (m):**	--

Sample Setup

Initial Sample Height, in	7.375
Mold Diameter, in	10.00
Sample Area, in^2	78.54
Wet Sample Weight, g	19,655.5
Wet Sample Weight, lb	43.34
Dry Sample Weight, g	17,208.5
Dry Sample Weight, lb	37.94

Initial Sample:
Moisture Determination

Tare	10
Wet Weight and Tare, g	990.18
Dry Weight and Tare, g	882.99
Tare Weight, g	129.16
Moisture Content, %	14.2

Initial Sample Density and Void Ratio

Specific Gravity[1]	2.70
Initial Sample Volume, ft^3	0.335
Initial Wet Density, lb/ft^3	129.3
Initial Dry Density, lb/ft^3	113.2
Initial Void Ratio	0.49

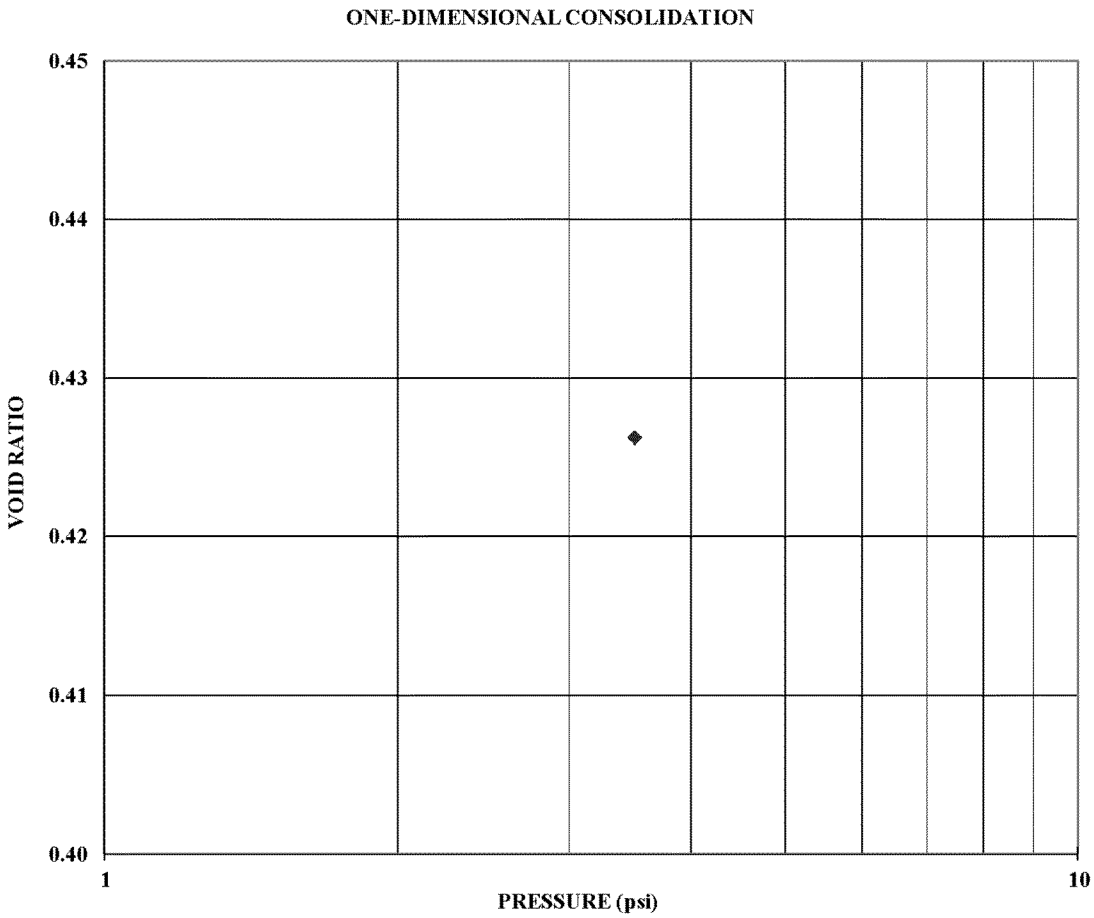
Final Sample Density and Void Ratio

Final Sample Height, in	7.067
Final Sample Volume, ft^3	0.321
Final Dry Density, lb/ft^3	118.1
Final Void Ratio	0.43

Load (psi)	Height (in)	Dry Density (pcf)	Void Ratio	Flow Rate (ml/sec)	Gradient	Permeability (cm/sec)	Porosity
3.5	7.067	118.1	0.43	2.65	2.18	3.6E-03	0.30

<u>NOTES</u>: [1]Specific Gravity = Assumed Value

October 2015 Golder Associates Inc. 1407886

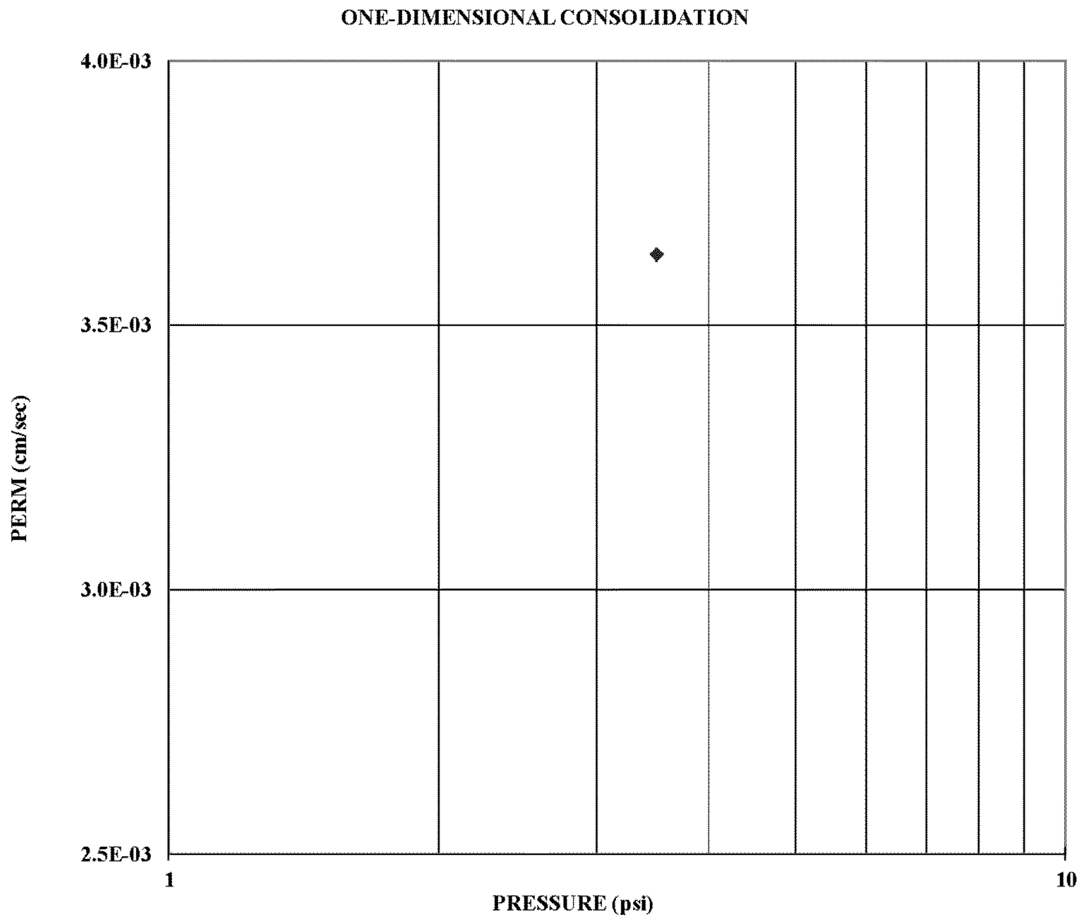


SAMPLE #	#1
USCS Description (ASTM D 2487):	Clayey gravel with sand, yellowish brown, moist

USBR/Lab Testing - 2014/CO
1405578

DATE	10/2/2015
TECH	MGC
REVIEW	MB

GOLDER ASSOCIATES INC.
LAKEWOOD, COLORADO

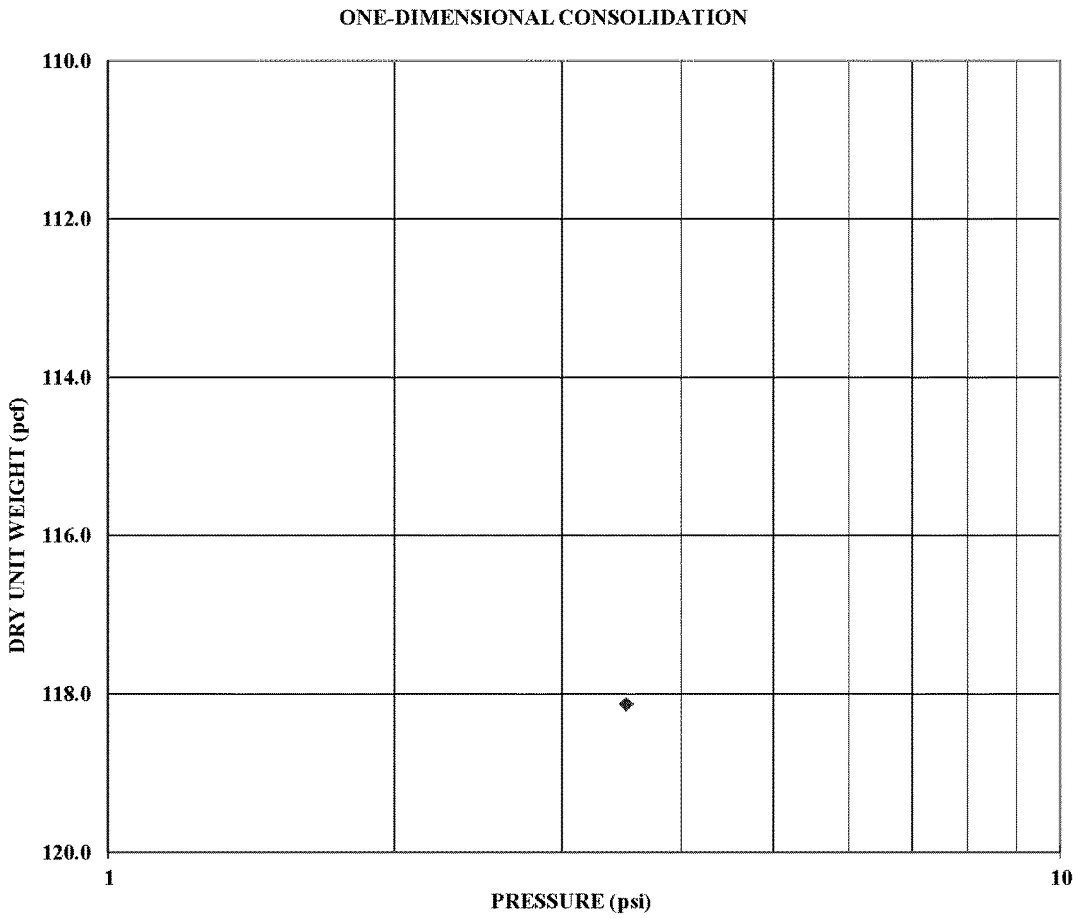


SAMPLE #	#1
USCS Description (ASTM D 2487):	Clayey gravel with sand, yellowish brown, moist

DATE	10/2/2015
TECH	MGC
REVIEW	MB

USBR/Lab Testing - 2014/CO
1405578

GOLDER ASSOCIATES INC.
LAKEWOOD, COLORADO



SAMPLE #	#1
USCS Description (ASTM D 2487):	Clayey gravel with sand, yellowish brown, moist

USBR/Lab Testing - 2014/CO
1405578

DATE	10/2/2015
TECH	MGC
REVIEW	MB

GOLDER ASSOCIATES INC.
LAKEWOOD, COLORADO

Golder Associates

October 1, 2015 Our Ref.: 1405578

United States Bureau of Reclamation
P.O. Box 25007
Denver, CO 80225

Attention: Chris Gemperline

RE: LABORATORY TEST RESULTS FOR USBR PROJECT – GOLD KING MINE

Dear Mr. Chatfield:

Golder Associates Inc. (Golder) has prepared this report to present the results of geotechnical laboratory testing conducted at Golder's Soils Laboratory in Lakewood, Colorado. This report presents the results of Hydraulic Conductivity testing on Sample "#2". All pending laboratory test results will be sent when testing has been completed.

Thank you for the opportunity to provide these laboratory testing services and we look forward to assisting you on any future projects.

Should you have any questions or comments, please do not hesitate to call.

Sincerely,

GOLDER ASSOCIATES INC.

Matt Barrett

Matt Barrett
Lab Manager/Senior Consultant

cc: File

mjb/MJB

Attachments (4 pages)

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USBR/LAB TESTING - 2014
1405578

RIGID-WALL COMPRESSION
FALLING-HEAD PERMEABILITY
10-INCH DIAMETER CELL

Project Title:	USBR/Lab Testing - 2014/CO	**Boring:**	--
Project Number:	1405578	**Sample:**	#2
Date Tested:	9/29/15 through 9/30/2015	**Depth:**	--

Sample Setup

Initial Sample Height, in	7.7015
Mold Diameter, in	10.00
Sample Area, in^2	78.54
Wet Sample Weight, g	21,424.4
Wet Sample Weight, lb	47.24
Dry Sample Weight, g	19,549.5
Dry Sample Weight, lb	43.11

Initial Sample: Moisture Determination

Tare	ABC-2
Wet Weight and Tare, g	961.34
Dry Weight and Tare, g	884.67
Tare Weight, g	85.25
Moisture Content, %	9.6

Initial Sample Density and Void Ratio

Specific Gravity[1]	2.70
Initial Sample Volume, ft^3	0.350
Initial Wet Density, lb/ft^3	135.0
Initial Dry Density, lb/ft^3	123.1
Initial Void Ratio	0.37

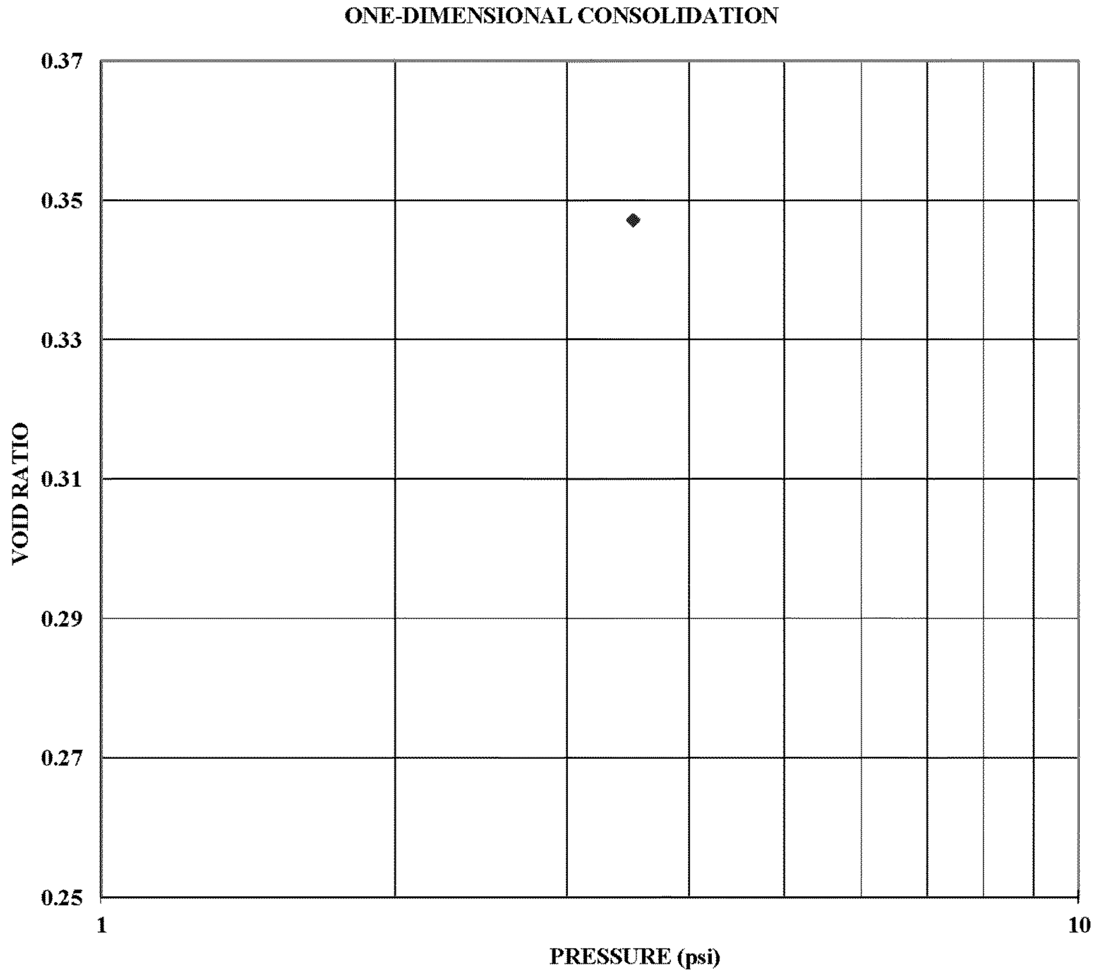
Final Sample Density and Void Ratio

Final Sample Height, in	7.584
Final Sample Volume, ft^3	0.345
Final Dry Density, lb/ft^3	125.1
Final Void Ratio	0.35

Load (psi)	Height (in)	Dry Density (pcf)	Void Ratio	Flow Rate (ml/sec)	Gradient	Permeability (cm/sec)	Porosity
3.5	7.584	125.1	0.35	--	--	3.4E-04	0.26

NOTES: [1]Specific Gravity = Assumed Value

October 2015 **GOLDER ASSOCIATES** 1405578

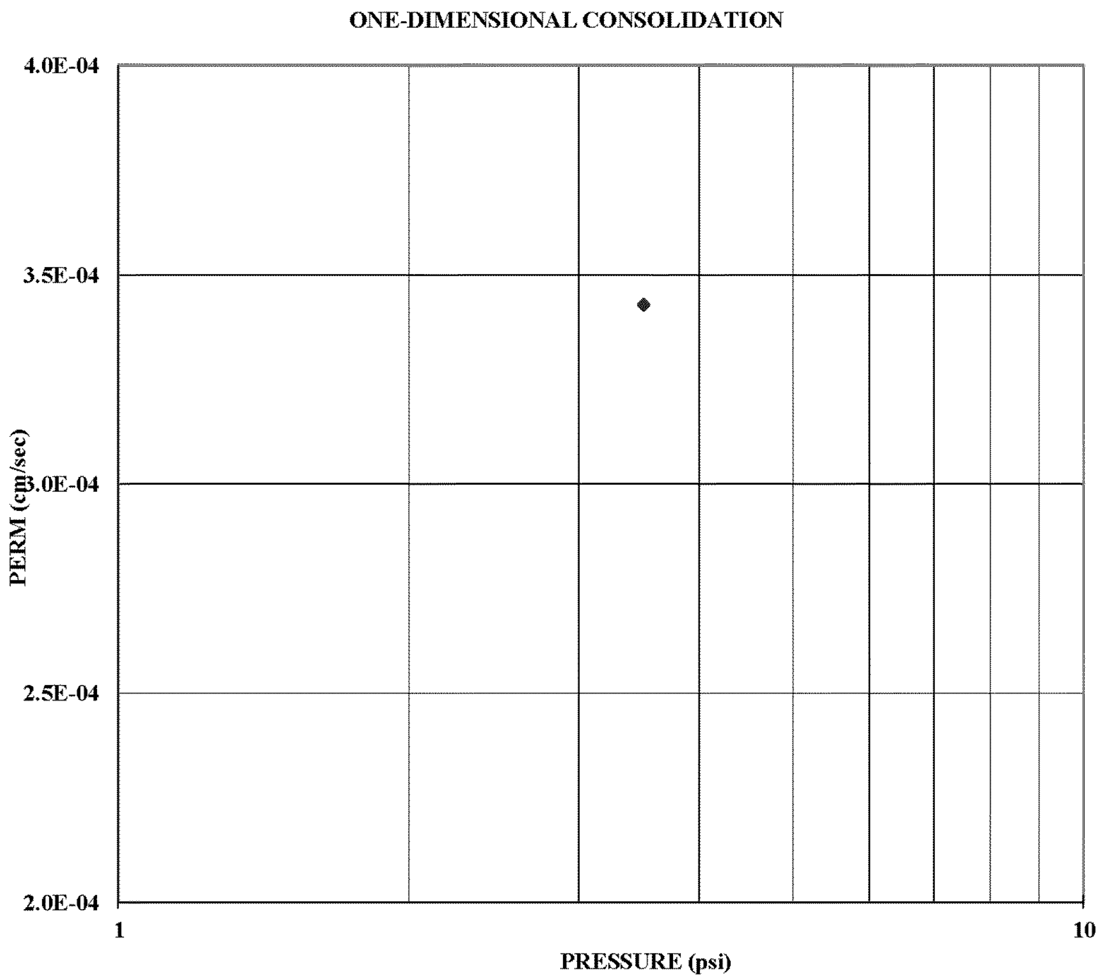


SAMPLE #:	#2
USCS Description (ASTM D 2487):	Clayey gravel with sand, yellowish brown, moist

DATE	10/1/2015
TECH	MGC
REVIEW	MB

USBR/Lab Testing - 2014/CO
1405578

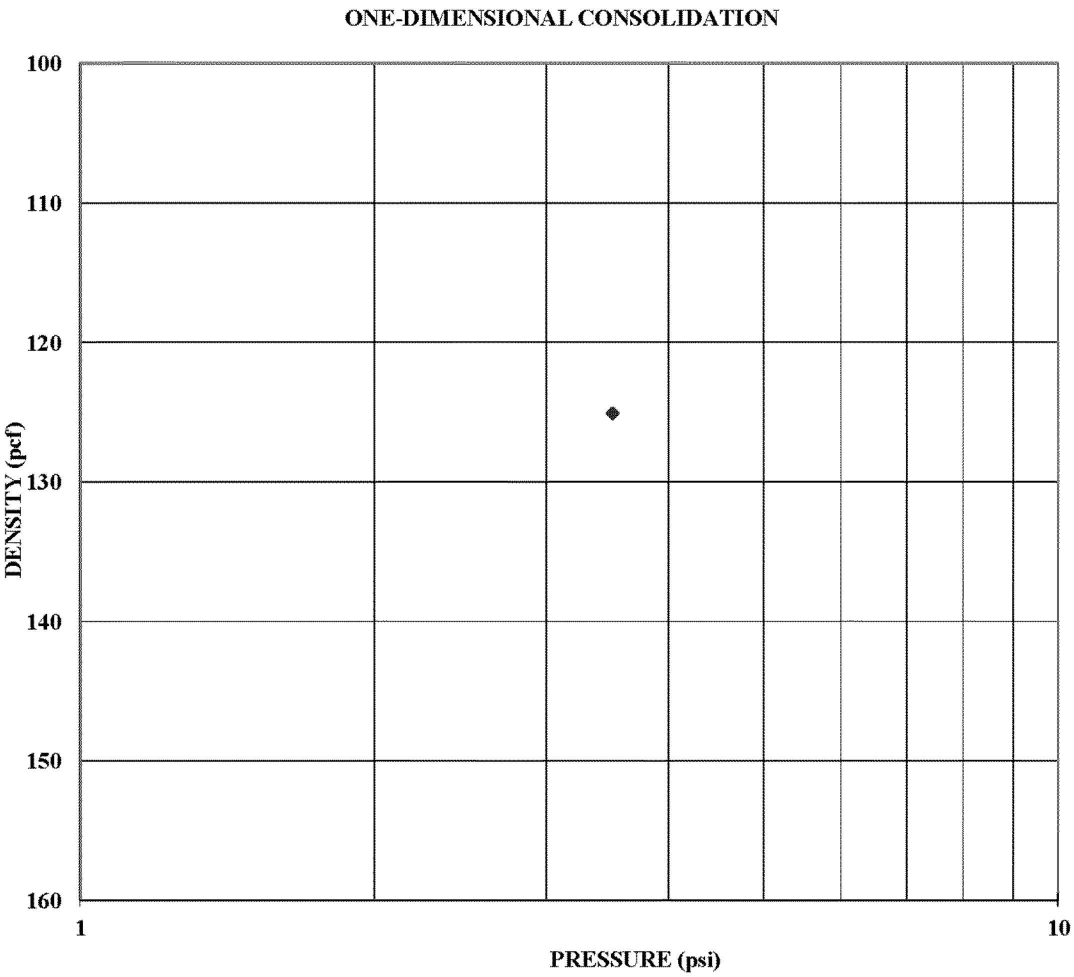
GOLDER ASSOCIATES INC.
LAKEWOOD, COLORADO



SAMPLE #:	#2
USCS Description (ASTM D 2487):	Clayey gravel with sand, yellowish brown, moist

	DATE	10/1/2015
USBR/Lab Testing - 2014/CO	TECH	MGC
1405578	REVIEW	MB

GOLDER ASSOCIATES INC.
LAKEWOOD, COLORADO



SAMPLE #:	#2
USCS Description (ASTM D 2487):	Clayey gravel with sand, yellowish brown, moist

USBR/Lab Testing - 2014/CO
1405578

DATE	10/1/2015
TECH	MGC
REVIEW	MB

GOLDER ASSOCIATES INC.
LAKEWOOD, COLORADO